Spatial and Temporal Trends in San Juan River Habitat

Final Report
2011 – 2015

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EXECUTIVE SUMMARY

The San Juan River in New Mexico and Utah has two endangered species of fish (Colorado Pikeminnow, *Ptychocheilus Lucius* and the Razorback Sucker, *Xyrauchen texanus*) that have life history requirements that include the use of low velocity and backwater habitats and areas of high habitat complexity, including secondary channels and islands. This study has monitored these habitats for 5 years adding to a database that began in 1992.

Habitat area and count were determined for 178 miles of the San Juan River. We monitored backwater, embayment, island and secondary channel types using a GIS geometric planform data system.

Two specific hypotheses were tested in this study. The first dealt with temporal trends in habitat features

> H_{01}: Under base flow conditions (<1,500 cfs), There has not been a temporal trend in the key habitats necessary for the two endangered species in the San Juan River

and the second with antecedent flow conditions.

> H_{02}: The antecedent conditions related to the hydrograph are not related to key habitat densities in the San Juan River under the following base flow conditions (<1,500 cfs)

Utilizing data collected in this investigation combined with the historical data since 1992, have resulted in the rejection of both null hypotheses ($p=0.05$), in that significant negative correlations were found between habitat densities (backwaters, secondary channel types, total wetted area) and time. The habitat losses may in part be attributed to antecedent flow conditions associated with reduced peak flows and spring runoff characteristics.

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INTRODUCTION

Colorado Pikeminnow (*Ptychocheilus lucius*) and the Razorback Sucker (*Xyrauchen texanus*) are two native fish species of the San Juan River listed as endangered in 1967 and 1991 respectively. A major component of the Endangered Species Act is the designation and protection of critical habitat, including locations within the geographical area occupied by the species that contain physical or biological features essential to the conservation of the species. These physical or biological qualities are considered primary constituent elements (USFWS, 1998). The US Fish and Wildlife Service determined critical habitat for the two endangered species in San Juan River to be from the confluence of the Animas River downstream to Neskahai Canyon (USFWS, 1998).

The historical range of the Colorado Pikeminnow and Razorback Sucker in the San Juan River has been fragmented by the construction and operation of several large dams (Navajo Dam and Glen Canyon Dam). Since dam closure in 1962, the flow regime in the San Juan River is now regulated by Navajo Dam releases.

In 1991, the U.S. Fish and Wildlife Service under a Section 7 consultation with the Bureau of Reclamation issued a biological opinion that required seven years of research on the San Juan River and its tributaries. Once completed, (Holden 2000), flow recommendations for Navajo Dam releases were made followed by the monitoring of the San Juan River's physical, biological, and chemical environment (Miller 2006). The San Juan River Recovery Implementation Program (SJRRIP) administers the recovery actions undertaken on the San Juan River.

As part of the SJRRIP several studies have documented habitats used by the various life stages of the two endangered species (Miller and Ptacek 2000). They found that adult fishes used very specific habitats that were in complex areas. Habitat use changed by season and flow. Specifically, on the descending limb of the hydrograph, adult Colorado Pikeminnow used embayments, backwaters, tributary mouths, and secondary channels. Ryden and Pfeifer (1995) found similar habitat uses for Razorback Suckers in the San Juan River.

Research in the upper Colorado River, Green River and Yampa River on young-of-year and juvenile Colorado Pikeminnow and Razorback Sucker have also shown that low velocity type habitats and backwaters were critical to their development (Holden 1977; Joseph *et al.* 1977; Tyus and Karp 1989; Tyus and Karp 1990). Currently in the San Juan River, an active stocking program for both species is underway with natural reproduction having been documented in recent years (Farrington *et al*. 2015).

Habitat monitoring (GIS based geometric planforms) started in the San Juan River in 1990 and 1992 with the initial work being conducted by the Bureau of Reclamation (Pucherelli and Clark 1990). The early mapping in 1990 only looked at total wetted area and backwaters. Data collected in 1992 was expanded to include secondary channels as well as backwaters and embayments (Pucherelli and Goettlicher 1992). The data were taken directly from videography without any field inspections. Since the fall of 1992, both airborne video combined with field mapping have been used to delineate habitat in the Juan River. This river wide mapping methodology (planform geometry) was based upon the work of Carter el al (1986) as well as Pucherelli and Clark (1990) and allowed mapping at a resolution of approximately 1 meter compared to over 2-3 meters in past efforts. The field mapping used 40 habitat categories within eight major habitat types. Between 1992 and 2007, river wide (Figure 1) habitat mapping was done 23 times at flows ranging from 479 cfs to 9,453 cfs. The river from river mile (rm) 2 to river mile (rm) 180 was mapped 17 times at base-flow conditions (<1,500 cfs).

In 2011 the San Juan Recovery and Implementation Program (SJRIP) revised the habitat monitoring protocols used in the annual SJRIP Monitoring Program (SJRRIP 2012). Those revisions were the result of a workshop held to determine the appropriate habitat monitoring protocols to meet the objectives of the SJRIP Long Range Plan. Workshop participants, including outside peer reviewers with specific expertise in habitat assessment combined with the SJRIP Biology Committee members, helped develop the protocols.

The San Juan River Recovery Implementation Program (SJRIP) is driven by several program guidance documents. The 2011 Monitoring Protocols state that the overarching goal for habitat monitoring is to:

"*Quantitatively document effects of naturally occurring conditions, management actions, and other anthropogenic activities on aquatic habitat availability in the San Juan River. Use this information to recommend appropriate modifications to recovery strategies for Colorado Pikeminnow and Razorback Sucker in the San Juan River.*"

In addition, there are statements in the Long Range Plan for specific tasks and objectives. The monitoring objectives relative to habitat are as follows:

1. *Track long-term trends of habitat availability.*

2. *Annually, following spring runoff, document abundance and distribution of key habitats and geomorphic features (backwaters, embayments, islands and total wetted area) that indicate the response of the river channel and habitat to antecedent runoff conditions and specific management actions*

3. *Develop relationships between habitat availability and antecedent flow conditions. Use key habitats for this analysis.*

The intent of this report is to address these three objectives.

The justification for selecting a subset of habitat types (embayments, backwaters, islands, and total wetted area), for monitoring was based on historical observations from the fishery and habitat monitoring programs (Bliesner *et al*. 2009; Bliesner and Lamarra 2007) where the captures of young-of-year (YOY) endangered fishes tended to positively correlate with channel complexity (Bliesner *et al*. 2009).

In addition, the San Juan River data integration analysis in 2005 (Miller 2006) indicated that complex channel reaches (those with high habitat diversity, islands, multi-threaded channels, and complex channel margins) was positively correlated with increases in native fish abundance.

From 2011 to 2015, habitats in the San Juan River have been mapped at only base-flows using the protocols described in the 2011 Annual Habitat Monitoring report (Lamarra and Lamarra 2011). Specifically, the monitoring focused on backwaters, embayments, and islands including their associated side channels.

The data presented herein are from 2011 to 2015 and represent the completion of this phase of the Habitat Monitoring Program for the San Juan River. We have also compared results with the entire habitat monitoring dataset (December 1992 to November 2007) were common parameters were measured.

Utilizing common parameters in the combined data sets, two null hypotheses were tested. Addressing these null hypotheses could result in management implications relative to the recovery of the two endangered fish.

The initial null hypothesis to be tested in this study was associated with the temporal trend in habitats:

> H_{01}: Under base flow conditions (<1,500 cfs), There has not been a temporal trend in the key habitats necessary for the two endangered species in the San Juan River

The second null hypothesis to be tested was associated with the relationship between habitat and antecedent hydrologic conditions:

> H_{02}: The antecedent conditions related to the hydrograph are not related to key habitat densities in the San Juan River under the following base flow conditions (<1,500 cfs)

METHODS

During the monitoring period 2011 to 2015 a variety of resources were used to obtain aerial images of the San Juan River (Table 1). In 2011, color digital video images with a resolution of approximately 10 centimeters were obtained with a recorder mounted in a BOR helicopter. Images were taken on September 21-22 from the confluence of the Animas River (rm 180) to the Clay Hills takeout area (rm 2) at a flow of 930 cfs, (Four Corners USGS Station 09371010). Using these photographs, the river was mapped in the laboratory without field inspections. The habitat monitoring protocols required that the river be mapped under base flow conditions (<1,500 cfs). In 2012, the river was again flown by the BOR on September 20-21 at a flow of 730 cfs. Several secondary channels between River Miles 148 and 130 were field verified as to their status (flowing or not flowing) because the images were partially shadowed. In 2013, the same method of image capture was used on August 28-29 at a flow of 1,500 cfs. The status of secondary channels for the entire river (River Mile 2-180) was field verified. However, in 2014 because of the unavailability of new videography, the 2012 video images were used and mapped in 2014 at a flow of 730 cfs. The entire river was field mapped by two crews on September 21-24. The final mapping event for the study was flown on November 7-10, 2015 using ortho-photos at a flow of 750 cfs.

Using Arcmap 10.0 (ESRI 2011), digital images were imported and post-processed in the laboratory, and subsequently overlaid on 2011 geo-referenced National Agriculture Imagery Program (NAIP) county mosaics for the full extent of the river floodplain boundaries. Each individual image was geo-referenced and rectified by first acquiring a minimum of 10 ground control points (GCP) on the NAIP images as references, and rectified using a spline raster transformation program. This transformation process optimized the

GCP local control point accuracy. Each individual image was rectified with a minimum of 20% overlap with the previous up-river image. The end product was a collection of geo-referenced, high-resolution (10 cm) images of the San Juan River from the Animas to Lake Powell (Figure 1). This initial process in preparing the mapping photos was similar to the methods employed by Block (2014) on the Little Colorado River. This post process methodology was used for the entire 2011 to 2015 aerial images.

During 2011 to 2013 of this study, the initial total wetted area for the San Juan River was determined by using the vector-editing program within Arcmap and the above-mentioned rectified, high-resolution images. Using the polygon function, a vector image of the water's edge was created for each mile and geomorphic reach in the San Juan River (Figure 1). These vectors were then transformed into an individual mile-specific polygon, from which a total wetted area could be determined. Islands (defined as any in-stream, non-wetted structure with at least 50% vegetation coverage) were delineated, as well as any non-wetted in-stream structures such as sand bars, cobbles bars, or debris piles. Once delineated, these areas were subtracted from the total wetted area to estimate the actual wetted area for each river mile in the system. Island structures were delineated per mile, and uniquely identified as part of the comprehensive data set. Characteristics such as count, area and perimeter were quantified. Backwater and embayment habitat types were also delineated using the same polygon-editing tool as referenced above, creating a unique vector image for each individual habitat. Both habitat types were considered part of the wetted area.

In 2014 and 2015, all habitat types were initially identified in the field and estimated on the rectified aerial images. Field delineated habitats were transferred into the computer via digitization as described above. Once digitized, all pertinent habitat and island structure locations, individual identifiers, areas and perimeters were exported from Arcmap into Microsoft Excel for analysis.

In addition to the acquisition of new habitat data for 2011 to 2015, an effort was undertaken to quantify the number and type of all flowing side channels. The following definitions of channel types were used to post process the entire habitat mapping data set from 1992 to 2015. Examples of these side channel types can be seen in Figure 2 for rm 151 in the San Juan River.

> ***Secondary Channel Split*** – A channel that contains less than 50% of the surface area of the river after bifurcation.
> ***Main Channel Split*** – A bifurcation of the main channel that contains approximately 50% of the surface area of the River
> ***Island Split*** – Channels that dissect islands under various flow conditions
> ***Cobble/Sand Bar Channel Splits***. Channels that are bifurcated due to the presence of non-vegetated cobble or sand bars.

Each individual channel split was defined by type, given a unique identifier and tracked over the entire period that mapping occurred in the San Juan River. In total, 28 individual mapping runs were characterized from December 1992 to November 2015 (historical and current mapping events). Each channel observation was scored as flowing (1) or not flowing (0). For each observation, flow at mapping was recorded.

As part of the data analysis, various hydrologic parameters were calculated from the hydrograph as gaged at the Four Corners USGS Station (09371010).

Antecedent conditions were defined as flows or hydrologic events that had occurred prior to habitat mapping for that calendar year and paired to the fall base-flow mapping period (Table 2). The antecedent conditions were calculated for each year from 1992 to 2015.

Data were analyzed using statistical tests from the StatPlus add-on to MicroSoft Excel. Recurrence intervals were calculated for annual peak discharges at two USGS gauges in the San Juan River. Archuleta (Station 09355500) and Farmington (Station 09365000) had different periods of record relative to the closure of Navajo Dam. Archuleta only had eight years of pre-closure data while the Farmington gauge (which includes the flows from the Animas River) had 38 years before dam closure (1962). The $Q_{1.5}$ (mean daily peak flow having a 1.5 year recurrence interval) was calculated using the methods suggested by Riggs (1968) and Castro and Jackson (2001). The post closure recurrence intervals were further divided into the pre and post San Juan Recovery Implementation Program (1991). The $Q_{1.5}$ recurrence interval has been suggested to be the return interval where the river flows are most effectively transporting sand and gravel. A reduction in the $Q_{1.5}$ indicates that the river has a reduced transport capacity (Simon *et al* 2004).

Historical channel planforms for a portion of the San Juan River floodplain (rm 88 to rm 91) was measured by digitizing floodplain features from old (USDA historical aerial photographs) and current aerial photographs (NAIP). This section of the river was selected because it represented a reach of the river that has been relatively undisturbed between 1934 and 2011. Five separate time periods were mapped. Wetted area and vegetation cover were quantified and summarized as m^2 per river mile.

Data summaries in this study were focused on the predefined geomorphic reaches of the San Juan River. The river was divided into eight reaches using a multivariate statistical approach, with reaches defined by characteristics of the riparian zone, in-stream habitat, and geomorphic features

Reach 1- (rm 0 to 16) is lowest reach of the San Juan River is under the influence of Lake Powell. This reach starts at the confluence with the lake and extends upstream to Slickhorn Canyon. Dominant characteristics include a low gradient, shifting sand bottom, unstable and ephemeral backwaters associated with sandbars, and several backwaters associated with side canyons. These backwaters are dependent upon rain events to flush out sandbars that form in the mouths of these dry washes.

Reach 2 - (rm 17 to 67) starts at Slickhorn Canyon and extends upstream to the mouth of the upper canyon. The reach is canyon bound with a single channel, high gradient with frequent rapids that are associated with debris fans from side canyons and ephemeral dry washes.

Reach 3 - (rm 68 to 105) is the lowermost reach that is not bedrock or canyon bound. It is characterized by low gradient, a broad floodplain abundant cobble riffles interspersed with sandbars, high sinuosity with multiple secondary channels and main channel splits, and large island complexes. The reach has numerous large backwaters associated with the secondary channels, but these backwaters are subject to filling with sand during summer storm events.

Reach 4 - (rm 107 to 130) is a transitional reach between the sandy Reach 3 and cobble dominated Reach 5. The characteristics are, a narrow valley bottom, large frequent islands, and stable secondary channels that result in low backwater abundance.

Reach 5 - (rm 131 to 154) is multi-channeled with the largest density of secondary channels compared to the other reaches resulting in the highest island count and area. The secondary channels are longer and more stable. There are numerous island-split channels resulting in a high degree of channel and habitat complexity. Backwaters, and embayments are numerous. Clean spawning cobble and gravels are present.

Reach 6 - (rm 155 to 180) is mostly a single channel with few secondary channels. If there are multiple channels, they are the result of a main channel split (equal flow around an island). The substrate is mostly cobble and there are numerous diversions with lateral dykes along the banks. The gradient is moderate with few backwaters and embayments. The upstream limit of this reach is at the confluence with the Animas River, the largest tributary to the San Juan River in the study area.

RESULTS

During the five years that habitat data were collected on the San Juan River between 2011 and 2015, the annual spring flows were below average. The wettest years were 2011 and 2015 with annual total runoff exceeding 870,000 ac. ft. Both years had flows that exceeded 8,000 cfs. The driest year was 2013 with an annual runoff of only 632,000 ac-ft and no days with a flow greater than 2,500 cfs (Figure 3 and Table 3). In terms of total runoff, 2012 and 2013 were the third and fourth driest years since 1992. The large spikes in flow after spring runoff are monsoonal storms that occur in the late summer and fall. These storms result in an influx of sand and silt into the San Juan through numerous dry washes.

Backwater Habitat

Backwater type habitats are the sum of backwaters and embayments. Backwaters are downstream facing low or zero velocity habitat that are surrounded on three sides by land. In the San Juan River, the majority of the larger backwaters (greater than 100 m^2) are associated with non-flowing secondary channels, main channel splits or island splits. Embayments are the same habitat except that they face upstream. However, there are numerous smaller backwater and embayment habitats that are associated with main channel cobble or sand bars. Typically, these habitats are less than 100 m^2.

As was noted in the reach descriptions, Reach 1 has been shown to be highly variable in terms of both surface area and counts of backwater type habitats (Tables 4 and 5). The main reason is that these habitats are associated with sand bars that are affected by small changes in stage (flow). Once the sand bars form, a stage change of only 10 centimeters can inundate or abandon these shallow backwaters. A second backwater type present in Reach 1 is associated with the mouths of dry washes. These washes provide large and deep backwaters. However, because of the low gradient and shifting sand, sandbars can block their entrance to the river. The dry washes must flow via storm events to reconnect to the river. The result of these factors is an unstable backwater environment in Reach 1 of the San Juan River.

Reach 2 had the lowest density of area and counts of backwater type habitats of all reaches in the San Juan River. The backwaters found in this canyon bound reach are relatively stable and are associated with debris fans deposited into the river from ephemeral washes (Tables 4 and 5).

Another way of looking at the backwater area and count differences between Reaches 1 and 2 is to calculate the densities, expressed as area (m^2) or count per river mile (Tables 6 and

7). Because the reaches are of different lengths, it provides a direct comparison in terms of relative backwater density. The data clearly shows that a significant difference exists in both area and count between the two reaches with Reach 1 having the higher densities and higher variability (higher standard deviations).

Reach 3 contained the highest surface area three out of the five years of monitoring backwater type habitats (Table 4). This non-canyon reach had numerous islands and associated side channels that were historically associated with the presence of backwaters and embayments. This reach also had the highest counts (Table 5) of all non-canyon reaches. Reaches 4 and 5 had similar backwater areas having an average of 330 m^2 per river mile in backwater densities. Reach 6 had the lowest backwater surface area with an average of only 175 m^2 per river mile. However, this difference when adjusted for river miles was not significantly different than the other non-canyon reaches (Tables 6 and 7).

The year-to-year variation in backwater surface area in the canyon reaches (Reach 1-2) has been has high as 15,000 m^2 (2013 to 2014). In the non-canyon reaches (Reach 3-6), the largest variation was only 9,000 m^2 (Table 4). In contrast to the canyon reaches that have shown a high degree of year-to-year variability in the loss or gain of backwaters, the non-canyon reaches have continuously lost backwater habitat from 2011 to 2014.

Island Habitat

Three parameters associated with islands were measured as part of the habitat-monitoring program. Island count (Table 8), island area (Table 9) and island perimeter (Table 10) were measured in each non-canyon reach for each year between 2011 and 2015. The canyon reaches did not contain islands.

Island count, which is a surrogate for habitat richness, was highest in Reach 3 and Reach 5. In 2011 and 2012, Reach 3 had the highest island counts, but during 2013, 2014 and 2015, Reach 5 had the highest counts (Table 8). Historically, these two reaches have had the most island complexes during base-flow monitoring. Because the quantity of islands is sensitive to ambient river flow, the higher 1,500 cfs flow during the 2013- mapping year, has complicated the analysis. In 2013, island count, area, and perimeters were the highest recorded over the five-year period (Tables 8, 9 and 10).

Island areas appeared to be relatively consistent between reaches and between years with the exception of 2013. Reach 6 lost over 50% of the island areas and counts in both 2014 and 2015.

Island perimeters ranged between 117,700 meters of edge (2014) to 197,426 meters (2013). The spatial and temporal patterns correspond to the island count and area data. When islands are present, their perimeters increase the channel edge by about 28% in the non-canyon area of the San Juan River

Channel Split Types

Secondary channels tended to be small in size relative to the main stream and separated from the main river for long distances (greater than a river mile). Reach 3 consistently had the highest count of flowing secondary channels (Table 11). This reach also has the lowest gradient and highest sinuosity of any non-canyon reach. Reach 6 had the lowest number of flowing secondary channels. As noted in the previous section, one of the characteristics of Reach 6 was the lateral dykes associated with irrigation diversions. These dykes have blocked many of the historical flowing secondary channels. During the study period, the number of flowing secondary channels in the non-canyon reach of the San Juan River ranged between 78 (2013) and 55 (2014 and 2015). Because secondary channels are also sensitive to flows at mapping (similar to islands), these data can be flow adjusted to look for temporal trends.

The highest numbers of main channel splits were found in Reach 6. This reach contained 50% of all main channel split types in the non-canyon reaches of the San Juan River (Table 12). The lowest numbers of main channel splits were found in Reaches 3 and 4.

Island splits are unique channels in that they are dividing an island that has already been defined by another pair of channels (secondary or main channel split). These channels tend to be short in length due to the size of the island. The highest densities (Table 13) were found in Reaches 3 and 5. Those are the reaches with the highest island counts. The lowest numbers were in Reach 6 where island perimeters were also lowest.

Cobble/Sand Bar splits (Table 14) were the most numerous and the shortest in length of the four channel types in the San Juan River during the study period. They tended to increase from Reach 6 (25 per year) down to Reach 3 (35 per year).

Total Wetted Area

Total wetted area (TWA) is a general category that includes all aquatic habitats as well as geomorphic features such as flowing secondary channel types. During the study period, the TWA ranged between 16.25 million m^2 and 17.62 million m^2. The highest surface area was in 2013, the year when mapping occurred at 1,500 cfs (Table 15). Given that islands and flowing channel splits maybe affected by flow at mapping, an analysis will need to be done to infer temporal trends in TWA.

Spatial differences in TWA were investigated by looking at the relative surface areas expressed as m^2 TWA per river mile in each reach (Table 16). The data clearly shows that Reach 1 had the highest area per mile of any reach while Reach 2 had the lowest area per mile. Since both Reaches 1 and 2 were canyon bound, these differences are striking. Reach 1 is high because the canyon bottom has been filled with 12-18 feet of sand and silt, thus raising the streambed. This raised bed has resulted in a wider stream course with numerous subsurface sand shoals. Reach 2 has been largely unaffected by sand deposition because the stream gradient is high in this reach, and any deposition is in the form of sand bars along the lateral edge of the stream. Reaches 3,4, and 5 are nearly identical in the amount of total wetted area per mile averaging almost 100,000 m^2 per mile. Reach 6 had the lowest TWA per mile of any non-canyon reaches averaging only 81,600 m^2 per mile. This reach had fewer secondary channel splits and has been affected by lateral dykes.

Historical Floodplain Planform

The first aerial photos were taken of the San Juan River between 1932 and 1937. Additional aerial photography occurred for sections of the river in the 1950’s, 60’s, 70’s and 90’s.

Analysis of the earliest photos confirmed that the San Juan River had a braided stream planform extending across the entire floodplain. Habitat features (total wetted area and vegetation cover) were quantified for a sequence of geo-referenced photos for a portion of Reach 3 at rm 88-91 (Figures 4). The location and photos were selected because they represented a portion of the floodplain that was relatively free from anthropogenic influences over the entire timeframe (1930's to the 2011). The results indicated that the San Juan River in the 1930's was a shallow braided stream that, through time, has narrowed substantially and stabilized with the establishment of vegetation in the floodplain. By the 1970's, the river was mostly single channeled with a few residual island complexes and secondary channels. From the 1970's to the 1990's, the river channel continued to narrow and simplify resulting in the total wetted area having a significant negative relationship with time (Figure 5). Concurrent with channel narrowing, the vegetation in the floodplain increased in density. In the 1930's riparian vegetation densities (expressed as a percent of the floodplain area per mile) were less than 10%. By the 1990's vegetation densities were almost 40% (Figure 6). The data shows that between 1950 and 1979 the riparian vegetation significantly increased from an average of 12% to 33% of the floodplain area followed by smaller changes between 1979, 1990 or 2011.

Regression Analysis and Temporal Trends in Habitat Planform

As stated previously, the initial null hypothesis associated with the temporal trend in habitats was as follows:

> H_{01}: Under base flow conditions (<1,500 cfs), there has not been a temporal trend in the key habitats necessary for the two endangered species in the San Juan River

To address H_{01}, an initial statistical analysis was performed using a regression approach. In the United States Geological Survey's Statistical Methods in Water Resources, Hersel and Hirsch (2002) discussed several methods for the analysis of temporal trends in hydrologic data. The simplest and most straightforward method was to test the above null hypothesis by determining if the slope(s) on simple or multivariable regressions (where time is the independent variable) was equal to zero at the p=0.05 level.

In this study, the test of H_{01} used only a subset of the data. It was of interest to investigate the temporal trend of the data at only base-flow conditions (<1,500 cfs at mapping). A simple linear model ***y = b+a(x)*** was used, where y is the habitat variable of interest (backwater area, island count, et cetera) and x is time expressed as days from the start of the data collections (December 1, 1992). Although results varied between Reaches (the most detailed spatial scale tested), significant negative trends with time were found for backwater area, backwater count, island count and total wetted area at p=0.05 (Table 17). In a similar manner, significant negative trends with time were found for secondary channel splits, main channel splits, and island splits, while cobble/sand bar splits were positively correlated with time (Table 18).

A multiple regression approach was also used as a basis for testing the null hypothesis of habitat trends with time (multiple regression linear model ***y = b+a(x)+c(z)***), where y is the habitat variable of interest (dependent variable) and x and z are independent variables (time and flow at mapping). This approach assumes that flow at mapping maybe a potential covariate influencing the dependent variables. The coefficient of determination (r^2) for the multiple regressions for the combined Reaches 3-6 (Table 17) increased compared to the simple linear regressions indicating that even at base-flow conditions, the influence of flow was present in the habitat observations. However, a similar multiple regression analysis using channel type densities (Table 18), did not result in increases in regression "r^2" values compared to the simple linear model.

Hersel and Hirsch (2002) have suggested that the influence of an exogenous covariate can be removed using the residuals from the covariate relationship (in our analysis, the flow at mapping) with the target dependent variables (in our analysis, habitat densities). Using that approach, the simple linear regression model was applied to the "Normalized" habitat density data and recalculated. In essence, the new model assumes that all habitat observations have been made at 915 cfs. In these simplified linear models, the null hypothesis of no temporal trend in habitat features is still rejected (Tables 19 and 20). The use of the covariate exclusion makes the observation of the linear model clearer to visualize and does not change the acceptance of a temporal reduction in critical habitat features. The r^2 value of the relationship between backwaters and time did not improve with the inclusion of flow in the multiple regression models or the use of covariate residuals. The main reason is that backwater area is independent of the flow at observation (Figure 7). Comparative graphs for island count (Figure 8), total wetted area (Figure 9), flowing secondary channels (Figure 10) and flowing island splits (Figure 11) are shown as examples where the use of residuals improved the trend relationship and did not alter the rejection of the null hypothesis of no trend with time (Slope =0).

Regression Analysis and Antecedent Conditions

The second major hypothesis to be tested in this study revolved around the possible mechanisms of habitat planform changes. To that end the null hypothesis was:

> H_{02}: The antecedent conditions related to the hydrograph are not related to key habitat densities in the San Juan River during base-flow conditions <1,500 cfs)

To address H_{02}, a multiple linear regression approach was used. In this instance, no normalization of the data was required in that flow was considered an independent variable as well as those antecedent conditions listed in Table 2. The five years of data collected in this study were combined with the historical data sets from 1992 to 2007. Only data from base-flow conditions (<1,500 cfs) were used in this analysis.

In the initial analysis, all potential independent variables were considered (antecedent conditions as well as flow at mapping and days from start). Only one dependent variable (backwater counts for Reaches 3 through 6) was not found to be significant (Table 21). All other dependent variables (backwater area, island counts, island area and island perimeter, total wetted area, and all channel types) were significantly related to various antecedent conditions as well as flow or days. The p value was <0.001 for all of the above equations. Although significant, main channel splits was the only significant equation not to contain a flow antecedent variable.

Across all dependent variables, the coefficient of determination (r^2) ranged from 0.58 to 0.93 for the significant equations, indicating that the independent variables were explaining a large amount of the variability in the dependent habitat variables.

The second analysis also used a multiple linear regression approach but removed flow and days as part of the step-wise regression process. Using a p=0.05 significance level, only backwater and island counts were not significantly related to an antecedent condition (Table 21). Although the r^2 values were less that 0.60, the regressions were significant. Secondary channel splits, main channel splits, island splits and area, island perimeter and total wetted area were all negatively influenced by the number of days the hydrograph was at various low flow metrics. This would indicate that the more days at low to intermediate flows, the less complexity in the river following spring runoff and summer base-flows. Backwater area had a positive relationship with the volume of water in the descending hydrograph.

The final series of step-wise multiple regressions were only calculated for backwater area, backwater counts, and total wetted area using all antecedent conditions as well as several geomorphic features. For backwater area, the descending hydrograph volume in combination with island count and the count of flowing island split channels had an r^2 of 0.76. The regression was highly significant (p=<0.001). The r^2 for the total wetted area equation improved from 0.46 to 0.90 with the addition of the number of flowing secondary channels (positive regression coefficient) and the number of cobble/sand bar splits (negative regression coefficient) and the number of days between 500-1,000 cfs (negative regression coefficient).

Using various multiple linear regressions, the null hypothesis for backwater count and island count could not be rejected (p>0.05). All the remaining habitat features were related to some antecedent features at the P=< 0.05 level (Table 21). Inclusion of some geomorphic features increased the significance of equations (p<0.05) for backwater area and total wetted area. Both equations included variables associated with islands or island complexes, further emphasizing the importance and interrelationship of backwaters and islands complexes.

DISCUSSION

The objectives for monitoring the distribution of habitats in the San Juan River were to better understand their persistence over time and the mechanisms of their formation. We have shown that geometric planforms (aquatic habitats) have been significantly reduced over the time period of the SJRRIP (1992 to 2015). The loss of key low velocity habitats, total channel wetted area and island complexes, is of concern relative to the recovery of the two endangered species, Colorado Pikeminnow and Razorback Sucker.

The river wide collection of habitat data in this study has extended the temporal trends in these habitats by eight years. The observations of key habitat features in the San Juan River now encompass a time span of 23 years. However, to better understand these relatively short timeframe changes in habitat features in the river, a longer historical perspective of the planform geometry of the San Juan River would be helpful.

Anecdotal evidence (oblique photos) have existed for the San Juan River since the early 1900's (Figures 12 and 13), and have shown a wide floodplain that contained a sand-bed river with numerous sand shoals and sparsely vegetated sand bars. Defining the timeframe and the processes from the historical sand bedded river to the current channel in an historical context will provide insights into possible management activities by the SJRRIP that may reduce or eliminate future habitat losses.

Using aerial photo interpretation for a section of the San Juan River floodplain, has yielded a temporal perspective of planform changes in the geometry of the San Juan River. These data overlap the current habitat collections that started in 1992. Combining both datasets provides an 80-year sequence of channel change for a four-mile section of the San Juan River. The data indicates that the reduction in the wetted area of the stream channel can be traced back to the 1930's (Figure 14) and is consistent with the conclusions drawn from this current study that channel simplification is occurring.

These observations of the historical changes in the San Juan River planform are also consistent with the results of other research on the early sedimentation and geomorphic conditions in the Colorado Plateau rangelands. As discussed by Hadley (1997), the sediment yields from the San Juan River at Bluff between 1930 and 1942 were almost two-thirds higher compared to the period from 1943-1962. He suggested that land use changes and a reduction in livestock grazing densities were possible reasons for the reduced erosion and sediment yields. Using data from the USGS gauge at Bluff Utah, he calculated that during 1930 to 1942, the San Juan River had a sediment yield of 41.7 million tons. From the same site during 1943 to 1962 sediment yields were reduced to 15.9 million tons, a reduction of 62%. Although several factors (reduction in precipitation, change in sample methodologies, and seasonal changes in precipitation) have been suggested as possible causes, the over-riding improvement in watershed vegetation condition was his conclusion for the sediment yield reduction. Graf (1986) examined data over a period 1930 to 1960 for the San Juan River and found that the variation in surface moisture conditions explained 66% of the variation in water and sediment yields while animal-grazing densities explained only 5%. Gellis et al. (1991) has suggested that a combination of the stabilization of arroyo incisions combined with aggradation and reduced precipitation in the 1940's permitted vegetation colonization in the valley floors.

A more recent study by Heins et al. (2004) looked at the temporal changes in upstream sediment loads from the San Juan River at the Animas confluence (start of Reach 6). They compared the sediment loading pre and post construction of Navajo Dam, 48 miles above the Animas confluence (Figure 15). Their analysis, using data from the Archuleta USGS gauge (Station 09355500) noted a drastic reduction in sediment loads following the closure of the reservoir. These loads decreased to only 0.8% of the pre-dam values (Figure 15)

Coincidental to sediment load reductions, there was an invasion of two exotic riparian species (Russian Olive (*Elaeagnus angustifolia)* and Salt Cedar *(Tamarisk spp))*. Both species have been present since the 1930's but were not well established in the San Juan River until the 1970's. The major increase in riparian vegetation cover noted between 1950 and 1979 (Figure 6) for the San Juan River has been attributed to these two species. Block (2014) had similar observations on the Little Colorado River using aerial imagery to map changes in channel form. She cites Robinson (1965) who chronicled the introduction and spread of salt cedar in the western United States starting in the early 1900's. In the San Juan River, Bliesner and Lamarra (1999) mapped the riparian corridor from Farmington (rm 180) to the confluence with Lake Powell (rm 2). They found that Russian Olives made up 37% and Tamarisk 30% of the riparian community. The native cottonwoods were only 7% and willows 6% of the plant community. The remainder of the riparian corridor was grass or bare ground.

To further complicate the analysis of possible causes of the observed channel simplifications, Navajo Dam was constructed and closed in 1962 and altered the natural flows of the San Juan River. The releases from the reservoir have reduced the frequency and magnitude of peak flows (Figure 16). Although only a few years of data were collected prior to closure at Archuleta, (USGS Station 09355500), the trend is evident. During the time period from 1963 to 1991, the reservoir was operated in a manner that eliminated frequent spring peaks and increased spring and summer base-flows. For the period of record prior to dam closure, the annual average peak daily flows were 8,230 cfs. From 1963 to 1991, the annual average peak daily flows were only 2,725 cfs. In 1992, flows were modified in an attempt to mimic a natural hydrograph as part of the San Juan River Recovery implementation Program (SJRRIP). Average annual peak daily flows have increased to 3,900 cfs. The average post-dam, pre-SJRRIP peaks were only 33% of the pre-dam peaks. The post-dam SJRRIP annual average peak daily flows have, on average increased to 47% of the pre-dam peaks.

Hydrologic data from Farmington (48 miles below the dam) had a much longer pre-dam period of record. This gauge (USGS Station 0936500) had 38 years of annual data prior to dam closure. Flows at this station include the Animas River as well as the San Juan River (Figure 17). The data from this site is similar to the data presented in Figure 16, in that, annual average peak daily flows were drastically reduced after 1962, primarily from a reduction in the San Juan River flows. At that time, the Animas River was unregulated. Annual average peak daily flows were 16,800 cfs prior to Navajo reservoir closing in 1992 and 8,300 cfs after (1963 to 1991). This represented a 51% reduction. Interestingly, the post 1991 dam operations produced almost identical annual average peak daily flows (8,740 cfs) at Farmington as the releases prior to the San Juan River Recovery Implementation Program subscribed flows.

The mean daily peak flow having a 1.5 - year recurrence interval, can be calculated from the data presented graphically in Figures 16 and 17. Given that we are interested in the channel stability and the change in channel complexity over time, the calculation of the $Q_{1.5}$ recurrence interval flow is of interest because it is often considered to be approximately equivalent to the *effective* or channel-forming discharge (Simon et al. 2004). It is the discharge that will transport the most sediment over the longest time period (Heins *et al.* 2004). The $Q_{1.5}$ calculated flow for the San Juan River under post Navajo Dam conditions was expanded to include the pre and post SJRRIP data. The calculations for the Archuleta station (dam releases) indicates that for the post dam pre SJRRIP, the $Q_{1.5}$ was 61% less than the pre dam value and 39% less during the SJRRIP flow release timeframe (Table 22.) These reductions indicate that the capacity of the San Juan River immediately below Navajo Dam to transport sand and coarser sediment has been greatly reduced following dam construction under both pre and post SJRRIP. The Farmington flows (with the Animas added) show the same pattern but less impact. The post dam calculated mean daily peak flow having a recurrence interval of 1.5 years ($Q_{1.5}$) for the pre SJRRIP time period and post dam-SJRRIP had reductions of 34% and 24% respectively (Table 22).

CONCLUSIONS

The impact from dams and their alteration of flow regimes and stream geomorphology has been well documented (Andrews 1996: Graf 2006). In his paper, Graf (2006) discusses the connection between hydrology and sediment and the impacts on functional surfaces as it relates to the regulation of rivers. Investigating 36 large dams in North America (9 from the western U.S. including Navajo Reservoir), Graf (2006) demonstrated that flow alterations resulted in significant reduction in the frequency of high flow channels, reduction in the active floodplain, reduction of low flow channels and frequency of low bars. He further notes that his results indicated that

> *"Regulated rivers have active, functional surfaces hydrologically connected to the channel that are much less extensive than along undammed rivers. The results pertaining to individual functional surfaces indicate that this reduction in active area is largely related to reductions in the sizes of active flood plains. The remaining active surfaces along regulated rivers are also simplified landscapes, because fewer functional surfaces occur than along regulated rivers. These outcomes imply that regulated rivers are shrunken, simplified versions of former unregulated rivers."*

The results of our investigations into the critical habitats (geometric planforms) in the San Juan River mirror his results. We have observed channel narrowing, low flow channel abandonment, and loss of complexity. This process has occurred over a time frame of at least 80 years but was accelerated at the same time as the closure of Navajo Dam. Modifications in sediment budgets, reductions in the magnitude and duration of peak flows, and the ability to do effective work (sediment movement) are believed to be causative factors. Using multiple linear regressions with antecedent hydrologic conditions as independent variables warrants further attention given their relationships to key habitat (planform) features.

The two null hypotheses that were tested in this study have been rejected for almost all habitat features. There have been significant decreases in key habitat features and channel complexity with time. Antecedent conditions related to low water flows (number of days with flows less than 750 cfs and the number of days between 500 and 1,000 cfs) were found to negatively impact total wetted area and island area. The volume of spring runoff in the decreasing hydrograph (June and July) was positively correlated to backwater area.

ACKNOWLEDGEMENTS

The authors would like to thank the members and peer reviewers of the San Juan River Recovery Implementation Program Biology Committee for their comments on the Habitat Monitoring Program. In addition, we would like to acknowledge the financial support of the Bureau of Reclamation and the project officer Mark McKinstry. In addition we would like to thank Keller-Bliesner Engineering and the Bureau of Indian Affairs for their involvement in the historical collection of the habitat data from 1992 to 2007. Lastly, we would like to acknowledge the participation of Dr. William Miller, Miller Ecological Consultants, for his collection and analysis of temperature data in this contract.

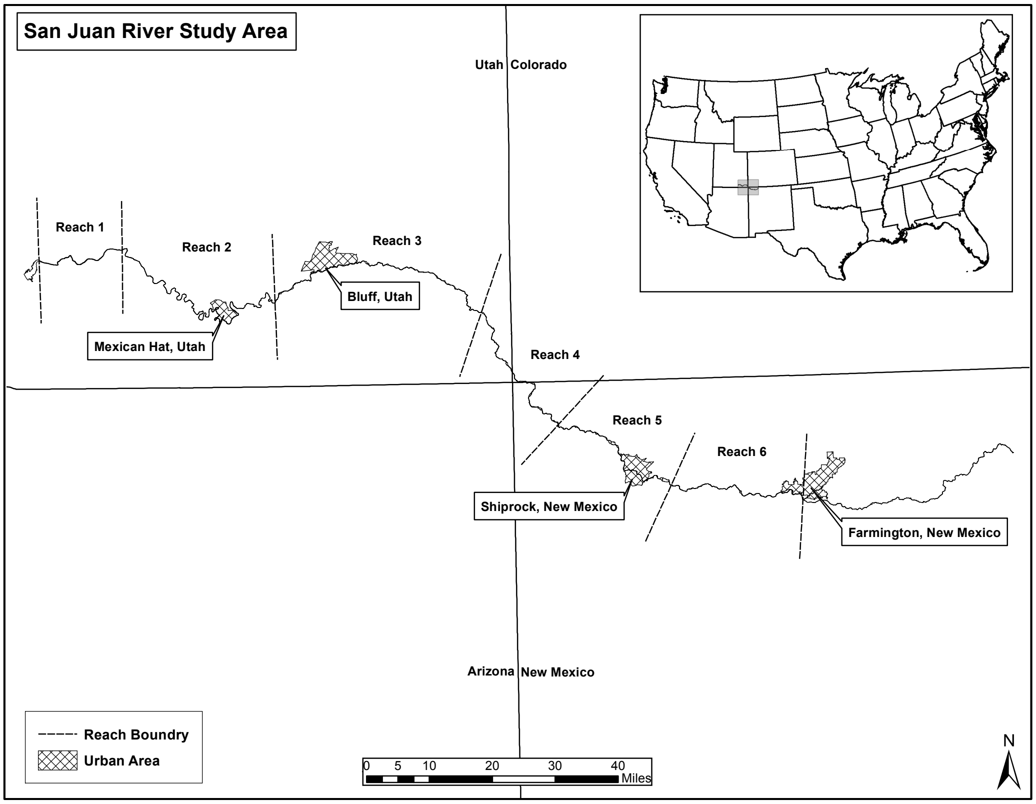


Figure 1: A location map of the San Juan River with the location of the river reaches.

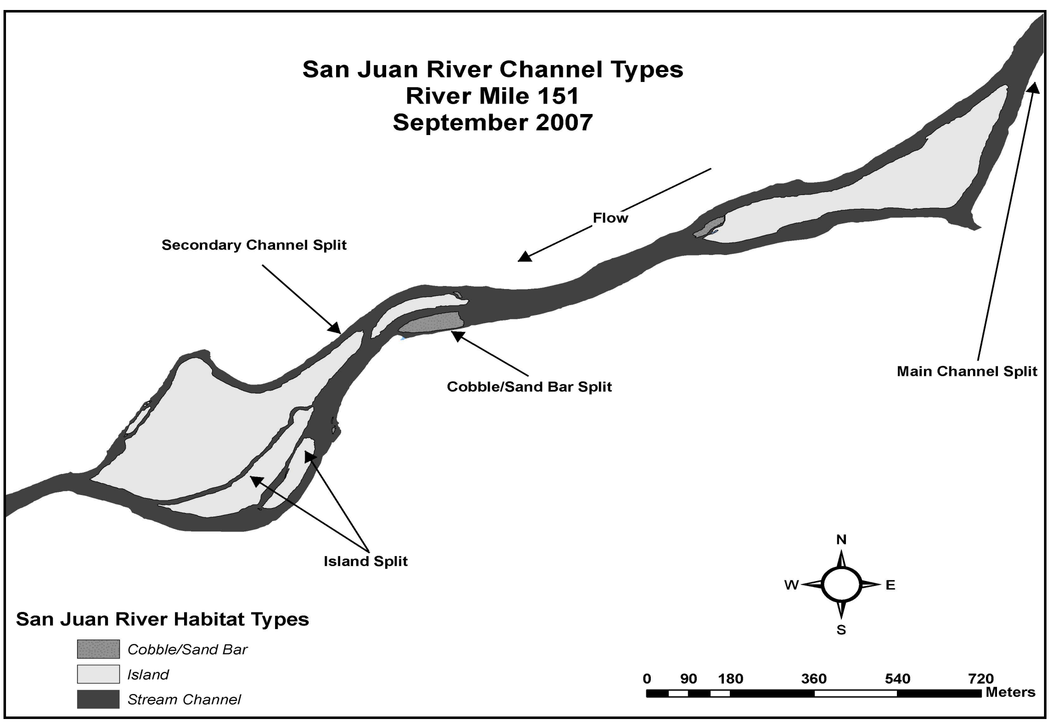


Figure 2: The different channel types in the San Juan River at RM 151 in September 2007

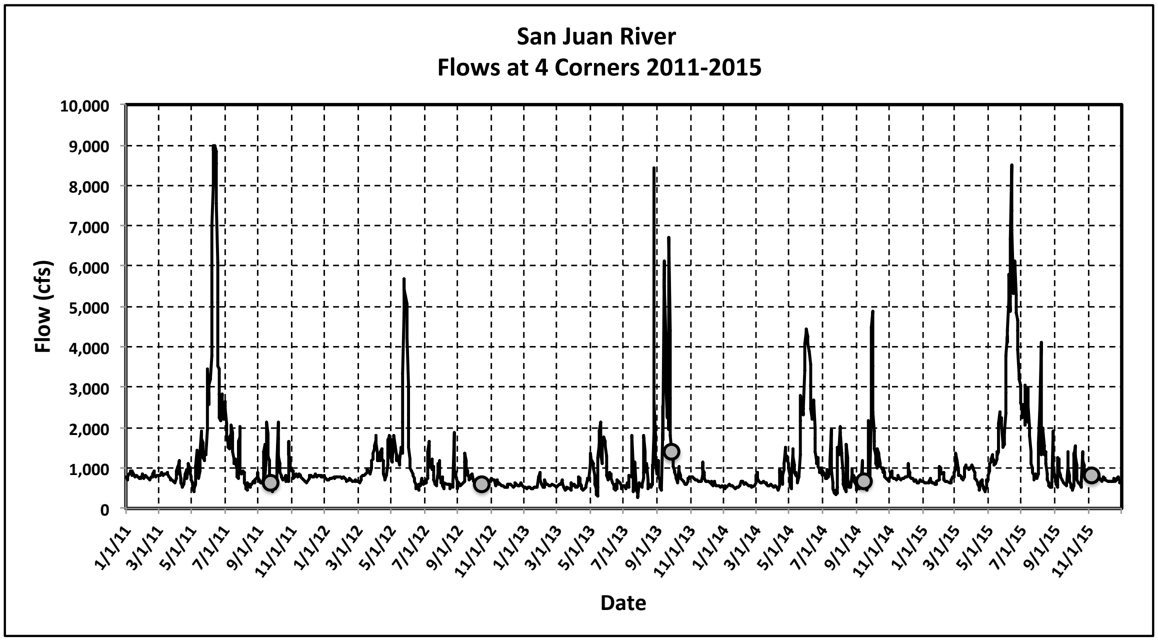


Figure 3: The hydrograph of the San Juan River at the 4-Courners gage (USGS Station 09371010) from January 1, 2011 to December 31, 2015. Mapping dates are shown as grey circles.

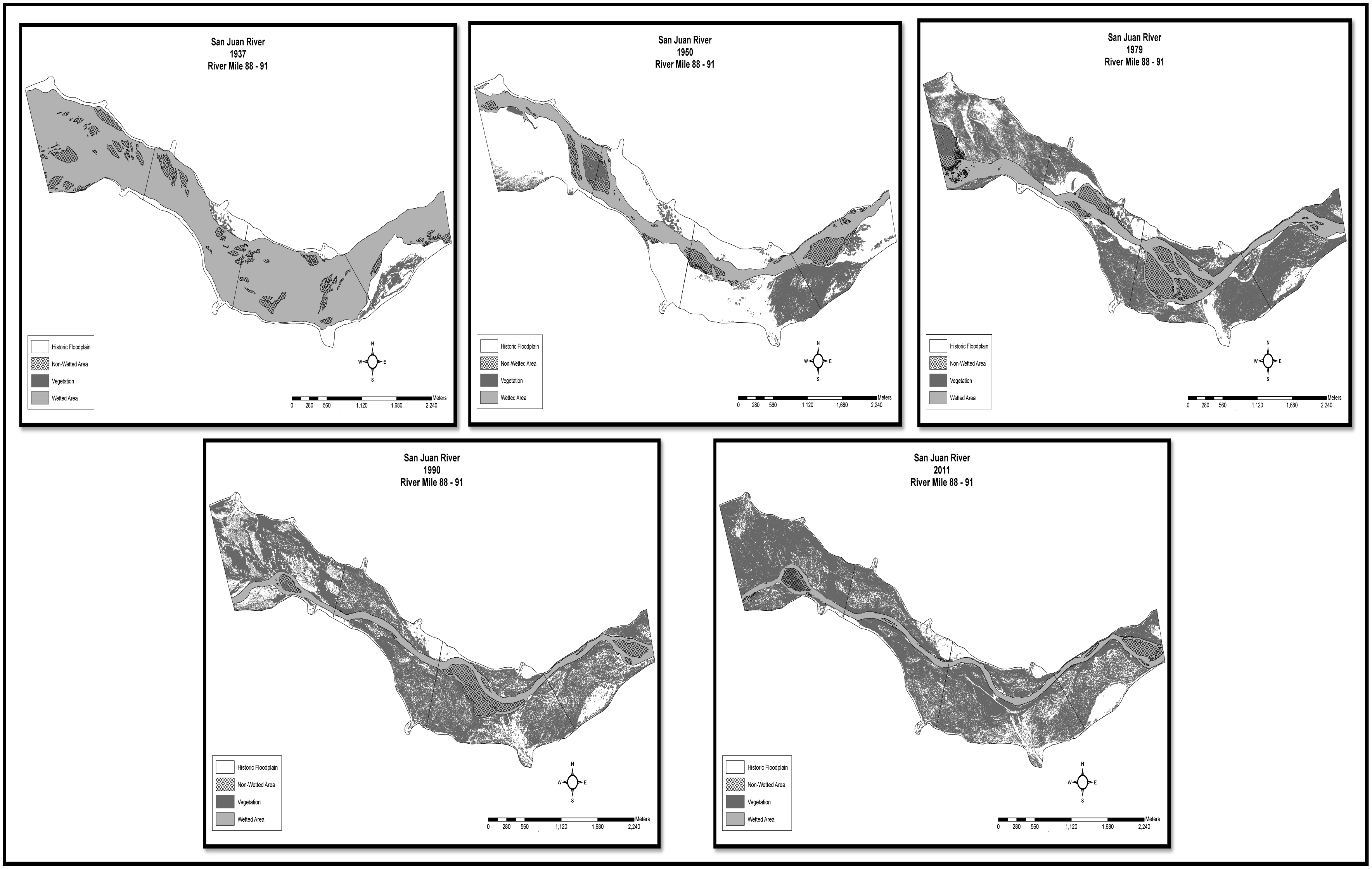


Figure 4: A planform view of the geometry of San Juan River starting in 1937. River mile 88 t0 91 were also mapped from aerial photos for 1950, 1979, 1990 and 2011. Mapping included the historical floodplain, wetted area, islands and riparian vegetation.

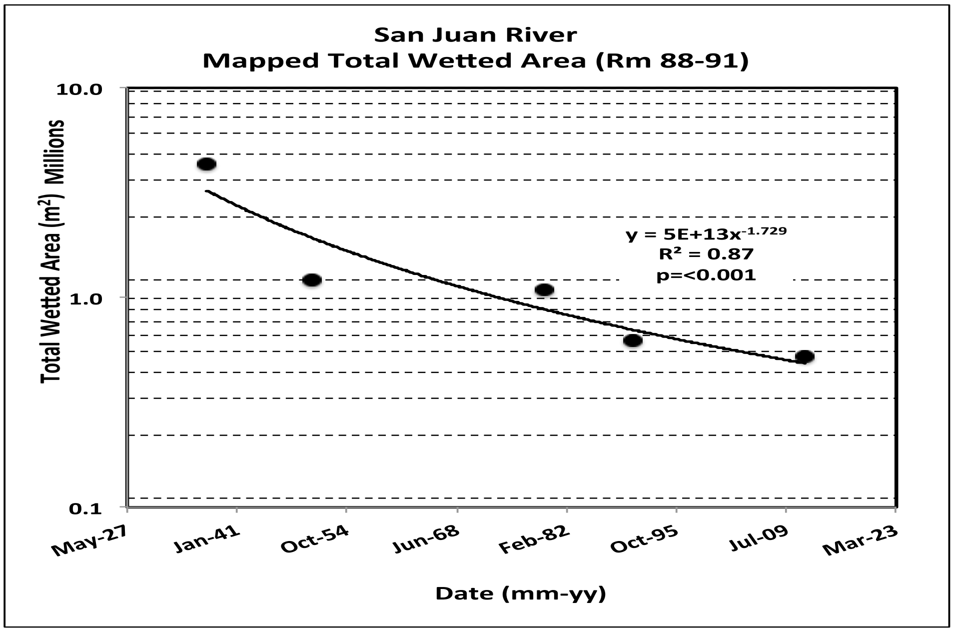


Figure 5: Comparisons of the Total Wetted Areas (TWA) of the San Juan River for the River Miles 88 to 91. Data are expressed as TWA for the four-mile reaches.

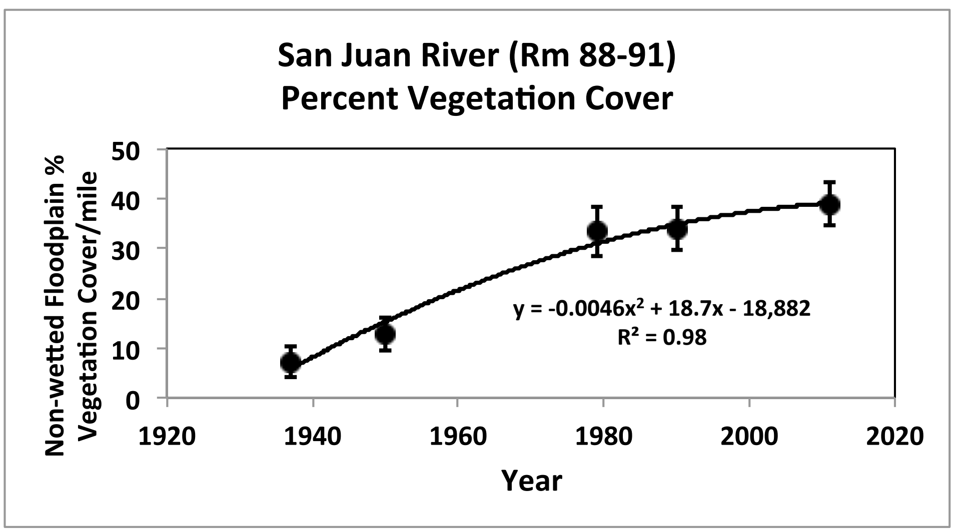
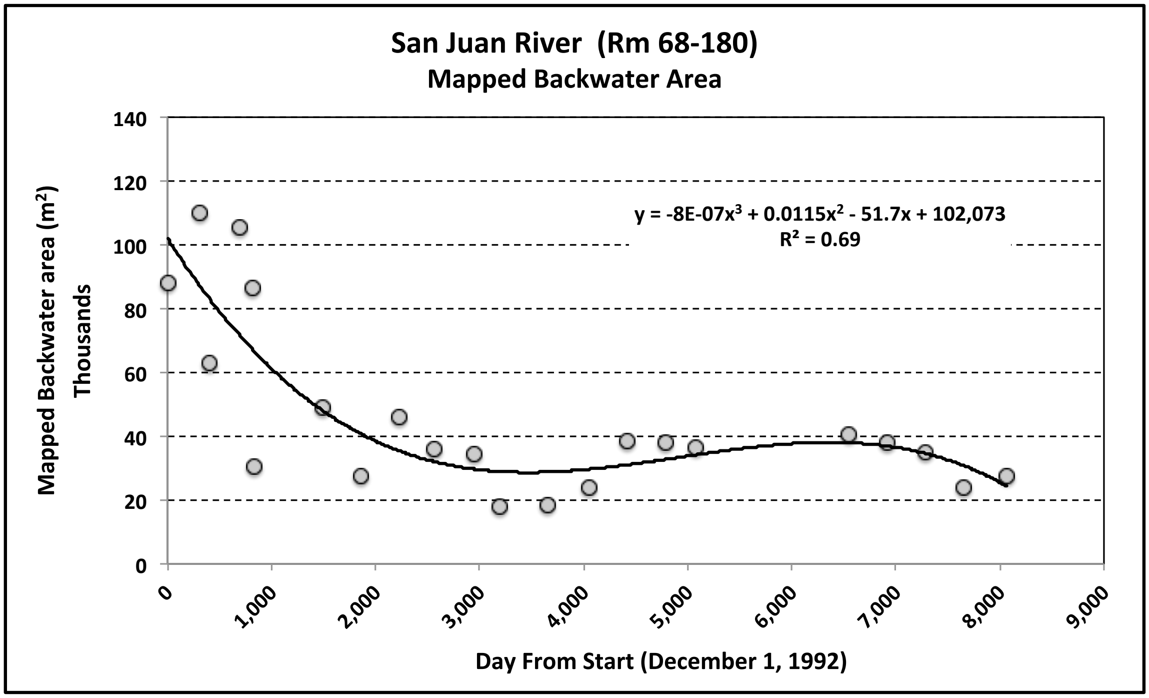


Figure 6: A comparison of the amount of vegetation (expressed as the percent of the non-wetted floodplain area per mile) for River miles 88 to 91 in the San Juan River. Data are the average and standard errors for the four miles of river for each mapping year.



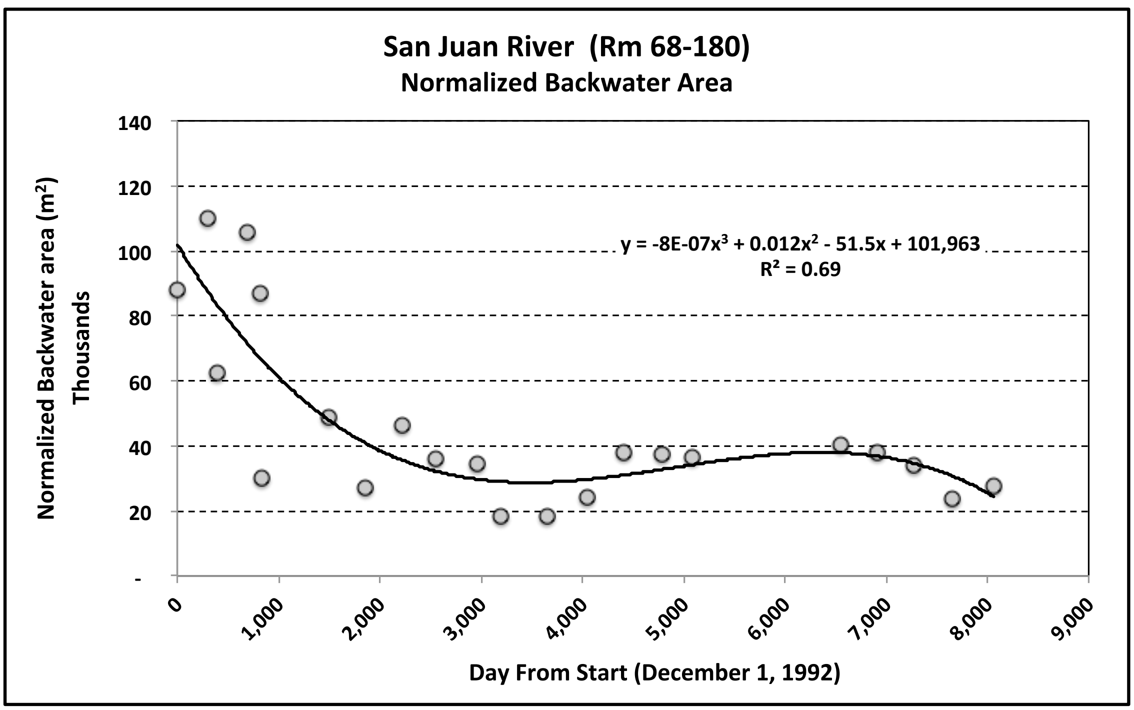
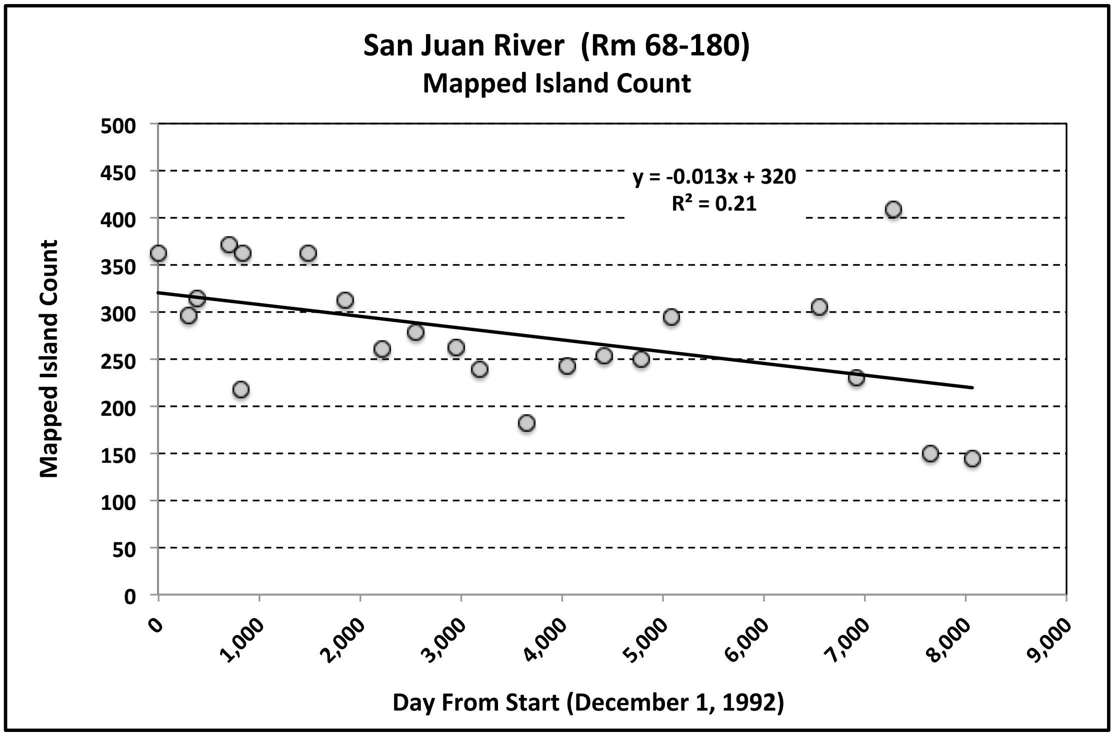


Figure 7: Thee relationship with time for backwater densities for the mapped data (above) and the normalized data (below) using flow residuals.



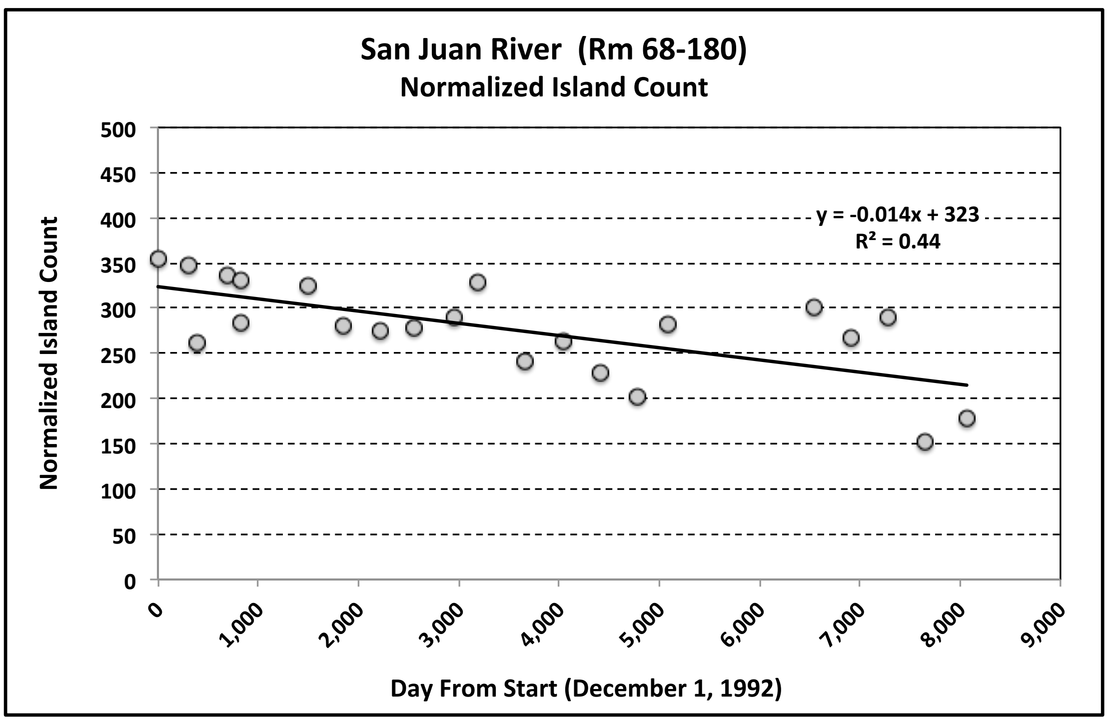


Figure 8: The relationship with time for island densities for the mapped data (above) and the normalized data (below) using flow residuals.

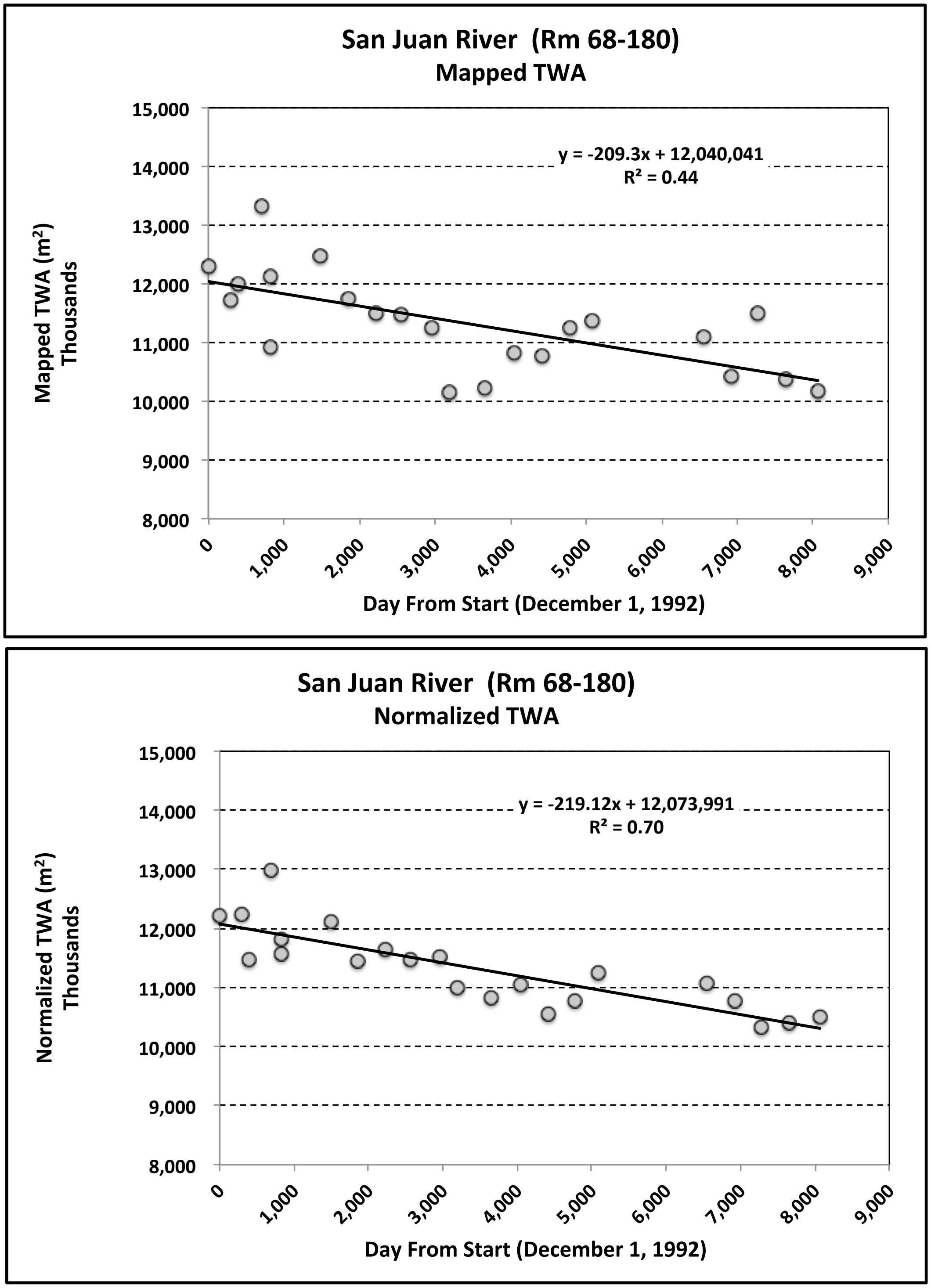
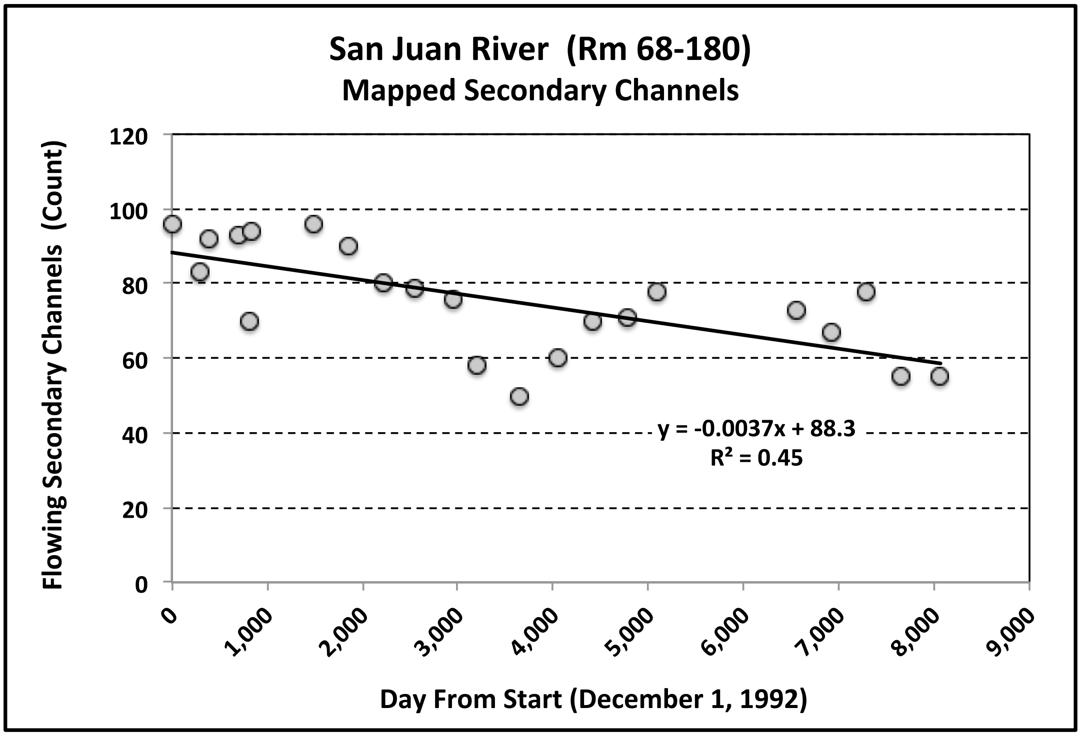


Figure 9: The relationship with time for Total Wetted Area (TWA) for the mapped data (above) and the normalized data (below) using flow residuals.



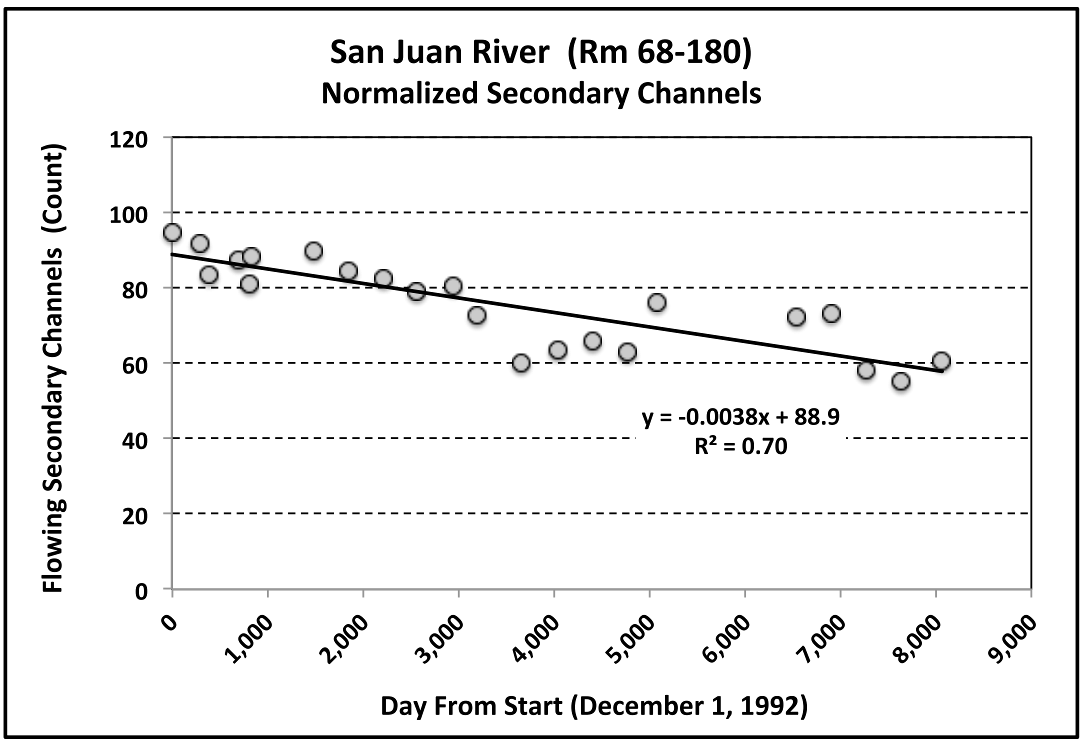
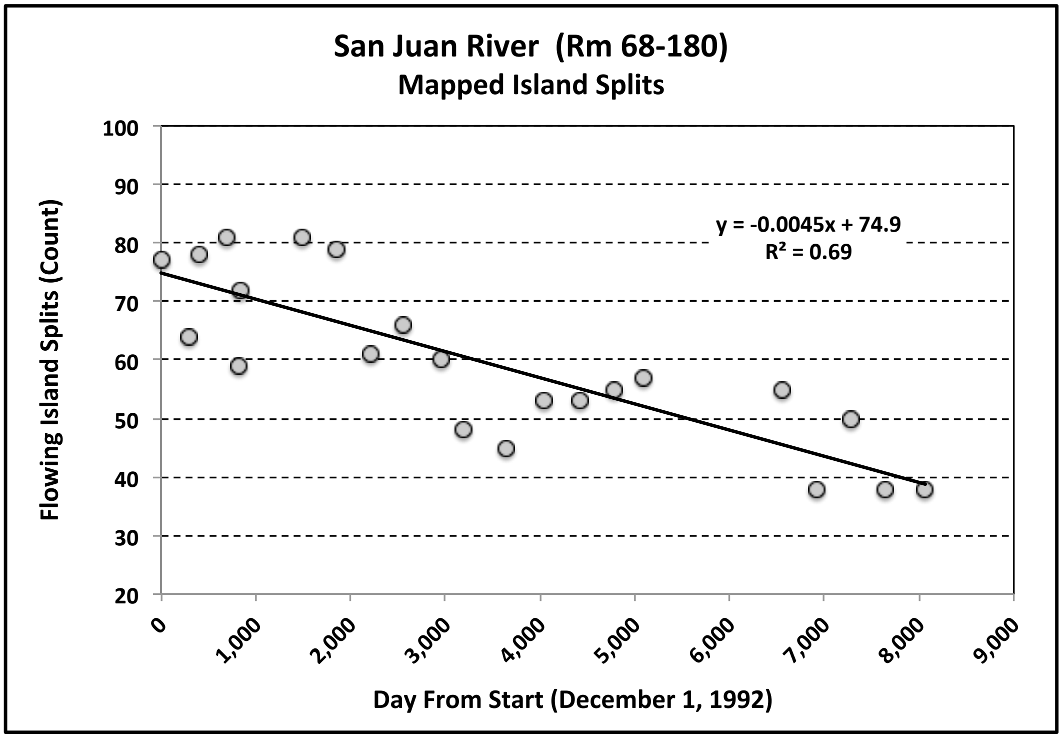


Figure 10: The relationship with time for flowing secondary channels for the mapped data (above) and the normalized data (below) using flow residuals.



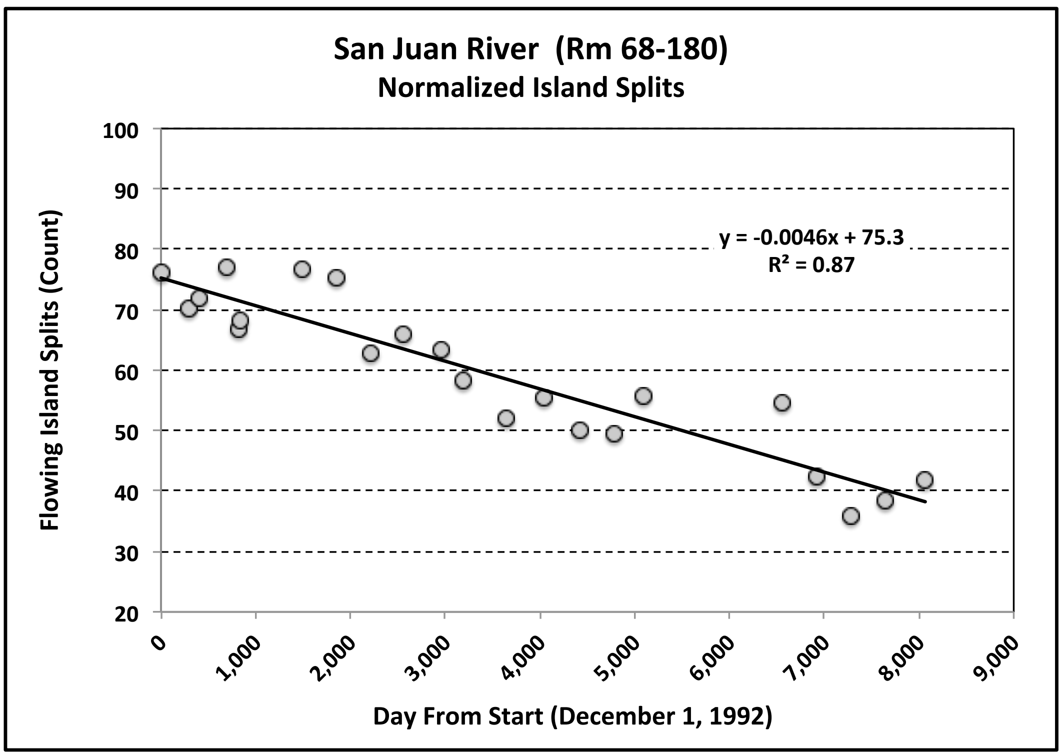


Figure 11: The relationship with time for flowing island split channels for the mapped data (above) and the normalized data (below) using flow residuals.

Figure 12: A photo of the San Juan River above Chinle Wash taken in the early 1900's. Note the wide stream channel and numerous sand bars and sand shoals.

Figure 13: A photo of the San Juan River from the goosenecks overlook taken in the early 1900's. Note the sand bedded stream with numerous sandbars and sand shoals. The river was perched above the current bedrock confined stream. This photo shows that the river had taken on a meandering pattern around sandbars that do not exist at the present time.

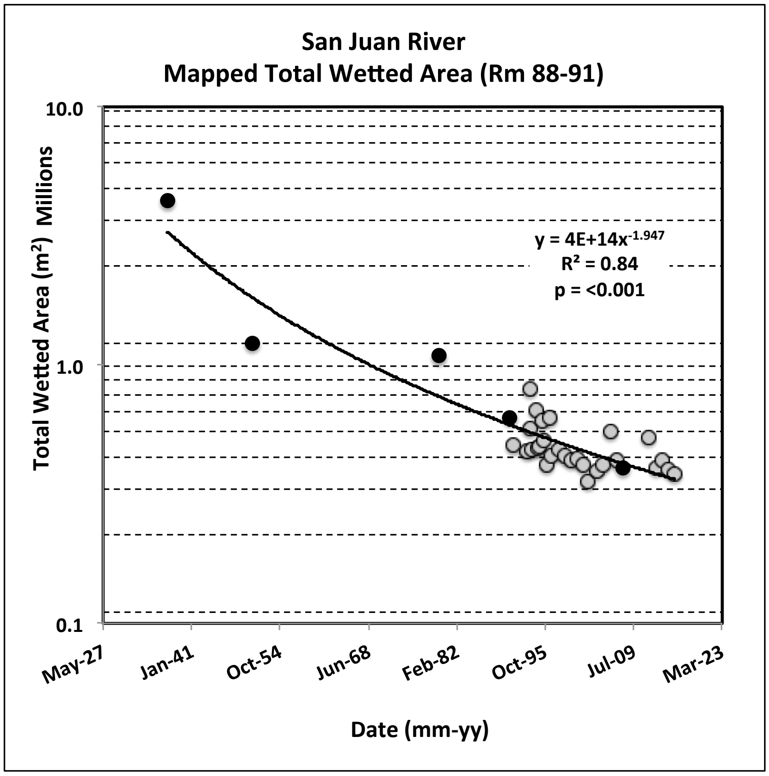


Figure 14: The comparisons of the Total Wetted Areas (TWA) of the San Juan River for the River Miles 88 to 91. Data are expressed as TWA for the four-mile reach. Solid dots are the historical air photo data while gray dots are for the same river miles extracted from this study.

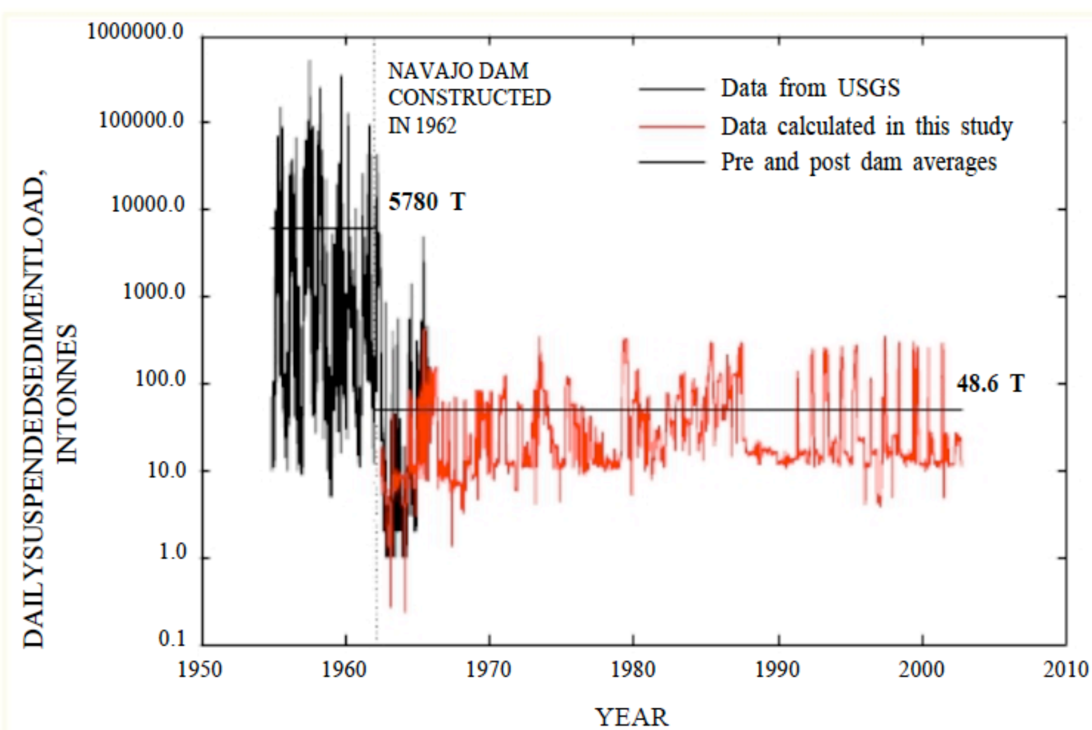


Figure 15: The sediment loading (tons per day) calculated at the Archuleta USGS gage (Station No. 09355500) before and after the closing of Navajo Dam (1962). Data and graph are from (Heins et al. 2004).

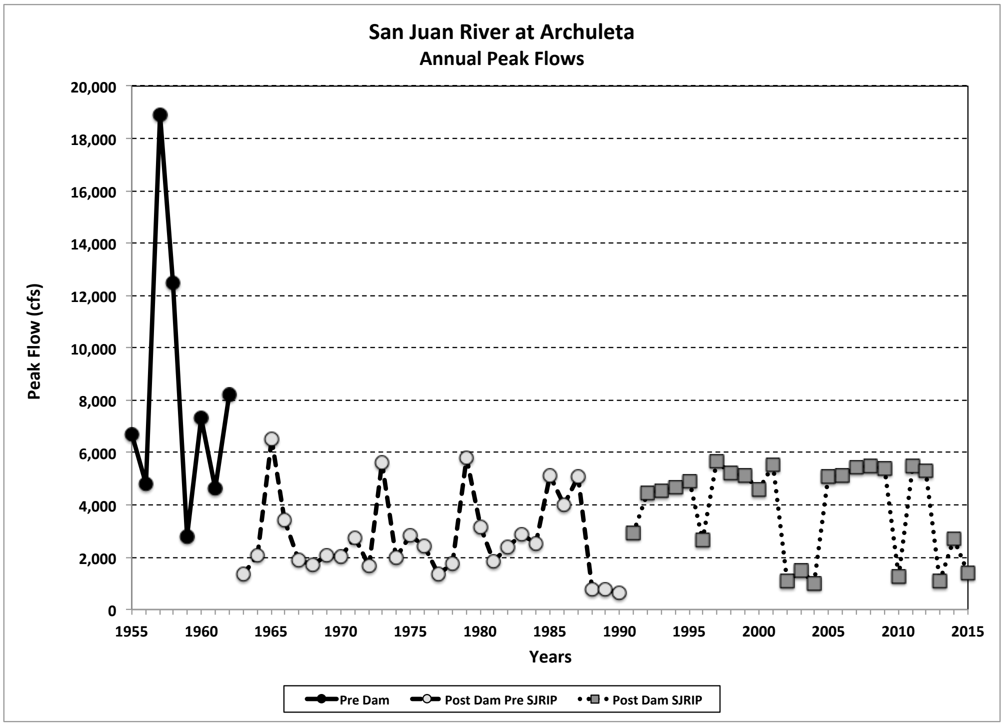


Figure 16: The annual maximum peak daily flows from the USGS gage at Archuleta (Station No. 09355500). Data are divided into three time periods: Pre-dam (1955-1962); Post dam, pre-SJRIP (1963-1991; and Post dam, SJRIP (1991-2015). Peak flows are expressed as cubic feet per second (cfs).

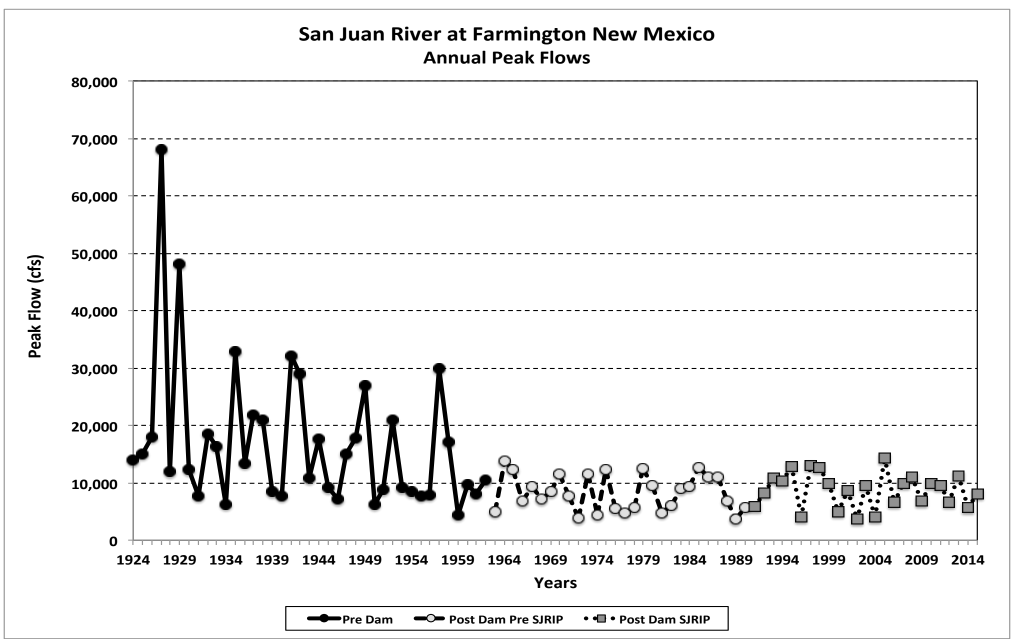


Figure 17: The annual maximum peak daily flows from the USGS gage at Farmington (Station No. 09365000). Data are divided into three time periods: Pre-dam (1924-1962); Post dam, pre-SJRIP (1963-1991; and Post dam, SJRIP (1991-2015). Peak flows are expressed as cubic feet per second (cfs).

Table 1: A summary of the sources of aerial images used in the San Juan River habitat mapping from 2011 to 2015. Flows at date flown and date mapped are also provided.

MAPPING YEAR	DATE FLOWN	IMAGE TYPE	FLOW (cfs)	DATE MAPPED	FLOW AT MAPPING (cfs)
2011	9/21-22/2011	HD Video	840-1,070	Laboratory (2011-2012)	930
2012	9/20-21/2012	HD Video	730	Laboratory (2012-2013) Field Verified Rm 148-130 (10/15/2012)	730
2013	8/28-29/2013	HD Video	1,500	Laboratory (2013-2014) Field Verified Rm 2-180 (9/23-26/2013)	1,500
2014	9/20-21/2012	HD Video	730	Field Mapped Rm 2-180 (9/14-17/2014)	730
2015	11/13-20/2013	Ortho-photographs	625-725	Field Mapped Rm 2-180 (11/7-10/2015)	750

Table 2: A summary of the antecedent conditions calculated from the annual hydrograph (calendar year) as measured at the USGS Station 09371010 at the Four Corners gage. In addition, habitat and channel geomorphic features are also provided. These data were calculated from the habitat mapping data.

ANACEDENT FLOW CONDITIONS	ABBREVIATIONS FOR REGRESSIONS
Days <=500 cfs	Days <500
Days<=750 cfs	Days < 750
Days<=1,000 cfs	Days <1,000
Days<=1,500 cfs	Days < 1,500
Days<=2,000 cfs	Days < 2,000)
Days<=2,500 cfs	Days < 2,500
Days Between 500 - 1,000 cfs	Days BT 500-1,000
Days Between 750 - 1,000 cfs	Days BT 750-1,000
Days Between 1,000 - 1,500 cfs	Days BT 1,000-1,500
Days Between 1,500 - 2,000 cfs	Days BT 1,500-2,000
Days Between 2,000 - 2,500 cfs	Days BT 2,000-2,500
Days >=2,500 cfs	Days > 2,500
Days >=5,000 cfs	Days > 5,000
Days >=8,000 cfs	Days > 8,000
Days >=10,000 cfs	Days > 10,000
Maximum Daily Flow cfs	Max Flow
Minimum Daily Flow cfs	Min Flow
Total Annual Runoff Flow (Jan 1 - Dec 31) (Ac Ft)	Total RO
Total Spring Runoff Flow (Mar 1 - July 31) (Ac Ft)	Spring RO
Assending RO (Mar 1-May 31) (Ac Ft)	Assending RO
Decending RO (June 1-July 31) (Ac Ft)	Decending RO

OTHER VARIABLES

Mapping Date as Days From Start (December 1, 1992)	Days
Flow at Mapping (cfs)	Flow
Secondary Channels Flowing at Mapping (Count)	SC
Main Channel Splits Flowing at Mapping(Count)	MC
Island Splits Flowing at Mapping (Count)	Island Splits
Cobble/Sand Bar Channel Splits Flowing at Mapping (Count)	CB/SB
Island Count at Mapping	Island Count
Island Area at Mapping (m^2)	Island Area
Island Perimeter at Mapping (m)	Island Perimeter
Total Wetted Area at Mapping(m^2)	Total Wetted Area

Table 3: The hydrograph characteristics from 2011 to 2015 as measured at the 4-Courners gage (USGS Station 09371010).

	Hydrograph Characteristics at 4-Courners Gage				
Antecedent Condition	**2011**	**2012**	**2013**	**2014**	**2015**
Peak Runoff (cfs)	8,980	5,680	2,140	4,890	8,490
Runoff (Mar-July af)	545,803	388,502	223,358	189,779	585,358
Total Runoff (Annual af)	871,147	674,917	632,705	721,912	939,320
Peak Date	13-Jun	25-May	20-May	3-Jun	12-Jun
Days > 10,000 cfs	0	0	0	0	0
Days > 8,000 cfs	7	0	0	0	1
Days > 5,000 cfs	12	6	0	0	14
Days > 2,500 cfs	27	10	0	23	38
Days BT 500 & 1,000	255	278	253	251	232
Days BT 750 & 1,000	157	79	45	79	77
Days BT 1,000 & 1,500	37	52	33	46	55
Days BT 1,500 & 2,000	22	18	17	10	14
Days BT 2,000 & 2,500	11	2	2	10	16
Days < 500	12	5	46	25	9
Days < 750	110	204	254	197	155
Days < 1000	267	283	299	276	241
Days < 1500	304	335	332	322	296
Days < 2000	326	353	349	332	310
Days < 2500	336	355	365	342	327
Maximum Daily Flow (cfs)	8,980	5,680	8,440	4,890	8,490
Minimum Daily Flow (cfs)	399	461	259	354	405
Assending RO (Mar 1-May 31) af	172,226	281,708	145,112	187,047	187,744
Decending RO (June 1-July 31) af	373,577	106,793	78,246	188,716	391,761

Table 4: The surface area (m2) of backwaters type habitats (backwaters plus embayments) in the San Juan River. Data are presented by reach and year. Flows at mapping are also provided.

BACKWATER SURFACE AREA AT MAPPING FLOWS							
REACH	Sep-11	Sep-12	Sep-13	Sep-14	Nov-15	Average	STDev
1	15,436	5,178	18,088	3,880	7,737	10,064	6,340
2	1,997	2,087	1,688	1,030	3,500	2,060	905
3	12,499	13,691	16,084	10,646	7,191	12,022	3,345
4	8,855	17,782	7,171	5,365	3,953	8,625	5,442
5	10,855	5,215	8,203	6,155	8,020	7,690	2,172
6	8,039	1,259	3,434	1,707	8,328	4,553	3,413
Canyon	17,434	7,265	19,775	4,909	11,237	12,124	6,387
Non-Canyon	40,248	37,947	34,892	23,873	27,492	32,890	6,967
River Total	57,681	45,212	54,667	28,782	38,729	45,015	11,797
Flow at Mapping	930	730	1,500	900	750		

Table 5: The count of backwaters type habitats (backwaters plus embayments) in the San Juan River. Data are presented by reach and year. Flows at mapping are also provided.

BACKWATER COUNTS AT MAPPING FLOWS							
REACH	Sep-11	Sep-12	Sep-13	Sep-14	Nov-15	Average	STDev
1	99	29	37	14	62	48.2	33.3
2	24	17	9	24	37	22.2	10.3
3	82	108	90	83	68	86.2	14.6
4	45	34	56	56	42	46.6	9.5
5	48	27	48	20	67	42.0	18.7
6	32	16	29	11	60	29.6	19.1
Canyon	123	46	47	38	101	71.0	38.4
Non-Canyon	207	185	223	170	237	204.4	27.3
River Total	330	231	270	208	338	275.4	58.0
Flow at Mapping	930	730	1,500	900	750		

Table 6: 4 The backwater surface area expressed as m² per river mile in each reach of the San Juan River.

BACKWATER SURFACE AREA AT MAPPING FLOWS (m^2/Rm)

REACH	Sep-11	Sep-12	Sep-13	Sep-14	Nov-15	Average	STDev
1	1,029	345	1,206	259	516	671	423
2	39	41	33	20	69	40	18
3	329	360	423	280	189	316	88
4	354	711	287	215	158	345	218
5	452	217	342	256	334	320	91
6	309	48	132	66	320	175	131
Canyon	264	110	300	74	170	184	97
Non-Canyon	356	336	309	211	243	291	62
River Total	322	253	305	161	216	251	66
Flow at Mapping	930	730	1,500	900	750		

Table 7: The backwater count expressed as the number of backwaters per mile for each reach in the San Juan River.

BACKWATER SURFACE AREA AT MAPPING FLOWS (m^2/Rm)

REACH	Sep-11	Sep-12	Sep-13	Sep-14	Nov-15	Average	STDev
1	1,029	345	1,206	259	516	671	423
2	39	41	33	20	69	40	18
3	329	360	423	280	189	316	88
4	354	711	287	215	158	345	218
5	452	217	342	256	334	320	91
6	309	48	132	66	320	175	131
Canyon	264	110	300	74	170	184	97
Non-Canyon	356	336	309	211	243	291	62
River Total	322	253	305	161	216	251	66
Flow at Mapping	930	730	1,500	900	750		

Table 8: The count of Islands in the San Juan River. Data are presented by reach and year. Flows at mapping are also provided.

TOTAL ISLAND COUNT AT MAPPING FLOWS							
REACH	Sep-11	Sep-12	Sep-13	Sep-14	Nov-15	Average	STDev
1	0	0	0	0	0	0	0
2	0	0	0	0	0	0	0
3	98	68	99	39	27	66	33
4	55	35	53	29	32	41	12
5	89	75	158	46	62	86	43
6	63	52	99	35	23	54	29
Canyon	0	0	1	0	0	0	0
Non-Canyon	305	230	409	149	144	247	112
River Total	305	230	409	149	144	247	112
Flow at Mapping	930	730	1,500	900	750		

Table 9: The area of Islands (m²) in the San Juan River. Data are presented by reach and year. Flows at mapping are also provided.

TOTAL ISLAND AREA AT MAPPING FLOWS							
REACH	Sep-11	Sep-12	Sep-13	Sep-14	Nov-15	Average	STDev
1	0	0	0	0	0	0	0
2	0	0	0	0	0	0	0
3	1,777,070	1,380,516	1,676,196	1,091,363	1,072,712	1,399,571	324,507
4	1,851,064	1,861,137	2,494,546	1,599,172	1,801,503	1,921,484	337,373
5	3,420,862	3,444,712	5,391,669	3,126,815	4,601,579	3,997,128	962,392
6	1,116,142	1,060,223	1,043,199	646,910	463,934	866,082	292,126
Canyon	0	0	0	0	0	0	0
Non-Canyon	7,949,555	7,531,188	10,390,476	6,464,190	7,939,730	8,055,028	1,439,089
River Total	8,165,138	7,746,588	10,605,610	6,464,260	7,939,730	8,184,265	1,506,075
Flow at Mapping	930	730	1,500	900	750		

Table 10: The perimeter of Islands (m) in the San Juan River. Data are presented by reach and year. Flows at mapping are also provided

TOTAL ISLAND PERIMETER AT MAPPING FLOWS

REACH	Sep-11	Sep-12	Sep-13	Sep-14	Nov-15	Average	STDev
1	0	0	0	0	0	0	0
2	0	0	0	0	0	0	0
3	49,870	37,980	48,279	27,520	27,115	38,153	10,894
4	41,291	36,761	51,774	31,369	34,167	39,072	7,985
5	45,649	49,842	71,913	40,311	53,888	52,321	12,054
6	27,649	23,950	25,459	18,500	14,665	22,044	5,332
Canyon	0	0	0	0	0	0	0
Non-Canyon	164,459	148,533	197,426	117,700	129,835	151,591	31,216
River Total	164,459	148,533	197,426	117,700	129,835	151,591	31,216
Flow at Mapping	930	730	1,500	900	750		

Table 11: The count of flowing secondary channels in the San Juan River. Data are presented by reach and year. Flows at mapping are also provided.

COUNTS OF FLOWING SECONDARY CHANNELS AT MAPPING FLOWS

REACH	Total Available	Sep-11	Sep-12	Sep-13	Sep-14	Nov-15	Average	STDev
1	0	0	0	0	0	0	0	0.0
2	0	0	0	0	0	0	0	0.0
3	92	30	24	28	18	17	23	12.9
4	50	17	17	24	16	16	18	5.3
5	63	17	17	18	15	15	16	2.6
6	23	9	9	8	6	7	8	4.7
Canyon	0	0	0	0	0	0	0	0.0
Non-Canyon	228	73	67	78	55	55	66	35.3
River Total	228	73	67	78	55	55	66	9.8
Flow at Mapping		930	730	1,500	900	750		

Table 12: The count of flowing main channel splits in the San Juan River. Data are presented by reach and year. Flows at mapping are also provided

COUNTS OF FLOWING MAIN CHANNEL SPLITS AT MAPPING FLOWS

REACH	Total Available	Sep-11	Sep-12	Sep-13	Sep-14	Nov-15	Average	STDev
1	0	0	0	0	0	0	0	0.0
2	0	0	0	0	0	0	0	0.0
3	13	9	8	8	7	8	8	4.2
4	10	9	7	9	6	6	7	1.2
5	13	10	9	10	8	8	9	1.5
6	20	20	20	20	18	18	19	5.5
Canyon	0	0	0	0	0	0	0	0.0
Non-Canyon	56	48	44	48	39	40	44	23.3
River Total	56	48	44	48	39	40	44	4.0
Flow at Mapping		930	730	1,500	900	750		

Table 13: The count of flowing island splits in the San Juan River. Data are presented by reach and year. Flows at mapping are also provided

COUNTS OF FLOWING ISLAND SPLITS AT MAPPING FLOWS

REACH	Total Available	Sep-11	Sep-12	Sep-13	Sep-14	Nov-15	Average	STDev
1	0	0	0	0	0	0	0	0.0
2	0	0	0	0	0	0	0	0.0
3	57	16	11	15	11	11	13	6.9
4	49	12	7	13	7	9	10	3.0
5	72	19	15	18	15	16	17	4.3
6	28	8	5	4	5	2	5	6.5
Canyon	0	0	0	0	0	0	0	0.0
Non-Canyon	206	55	38	50	38	38	44	23.7
River Total	206	55	38	50	38	38	44	7.7
Flow at Mapping		930	730	1,500	900	750		

Table 14: The count of flowing cobble/sand bar splits in the San Juan River. Data are presented by reach and year. Flows at mapping are also provided

COUNTS OF FLOWING COBBLE/SAND BAR CHANNEL SPLITS AT MAPPING FLOWS

REACH	Total Available	Sep-11	Sep-12	Sep-13	Sep-14	Nov-15	Average	STDev
1	0	0	0	0	0	0	0	0.0
2	0	0	0	0	0	0	0	0.0
3	65	40	34	38	33	38	37	19.4
4	42	30	29	25	27	30	28	5.1
5	32	25	25	28	21	25	25	2.8
6	42	24	26	26	26	21	25	2.2
Canyon	0	0	0	0	0	0	0	0.0
Non-Canyon	181	119	114	117	107	114	114	60.3
River Total	181	119	114	117	107	114	114	4.3

Flow at Mapping		930	730	1,500	900	750

Table 15: The total wetted area (m2) in the San Juan River. Data are presented by reach and year. Flows at mapping are also provided.

TOTAL WETTED SURFACE AREA AT MAPPING FLOWS

REACH	Sep-11	Sep-12	Sep-13	Sep-14	Nov-15	Average	STDev
1	3,546,901	2,194,744	2,153,395	2,224,198	2,039,165	2,431,681	627,379
2	2,153,939	3,694,245	3,969,715	3,649,718	3,795,063	3,452,536	736,284
3	3,957,507	3,738,218	4,136,032	3,685,948	3,569,930	3,817,527	226,907
4	2,566,007	2,387,334	2,670,892	2,350,428	2,371,517	2,469,235	141,776
5	2,389,249	2,198,231	2,490,000	2,240,150	2,191,584	2,301,843	132,043
6	2,190,224	2,089,094	2,195,364	2,099,425	2,043,307	2,123,483	66,729
Canyon	5,700,840	5,888,989	6,123,109	5,873,916	5,834,228	5,884,216	152,745
Non-Canyon	11,102,987	10,412,877	11,492,288	10,375,951	10,176,337	10,712,088	559,253
River Total	16,803,827	16,301,866	17,615,397	16,249,866	16,010,565	16,596,304	638,635

Flow at Mapping	930	730	1,500	900	750

Table 16: The Total Wetted Area (TWA) for each reach in the San Juan River expressed as m² per river mile within each reach.

TOTAL WETTED SURFACE AREA AT MAPPING FLOWS (m^2/Rm)							
REACH	Sep-11	Sep-12	Sep-13	Sep-14	Nov-15	Average	STDev
1	236,460	146,316	143,560	148,280	135,944	162,112	41,825
2	42,234	72,436	77,838	71,563	74,413	67,697	14,437
3	104,145	98,374	108,843	96,999	93,946	100,461	5,971
4	102,640	95,493	106,836	94,017	94,861	98,769	5,671
5	99,552	91,593	103,750	93,340	91,316	95,910	5,502
6	84,239	80,350	84,437	80,747	78,589	81,672	2,566
Canyon	86,376	89,227	92,774	88,999	88,397	89,155	2,314
Non-Canyon	98,257	92,149	101,702	91,823	90,056	94,797	4,949
River Total	93,876	91,072	98,410	90,781	89,444	92,717	3,568

Flow at Mapping	930	730	1,500	900	750

Table 17: The results of the simple linear regression model where x was time (expressed as days from December 1, 1992) and y was habitat features. Regressions were done for each reach as well as the entire non-canyon section (Reach 3-6). In addition, a multiple linear regression was performed with both time and flow.

San Juan River Non-Normalized Habitat Data

Habitat Type	Equation : Y = a + b(Days)	r^2	p	Equation : Y = a + b(Days)+c(Flow)	r^2	p
Backwater Area (m^2)	R3 = 27,905 -2.98 * Days	0.29	0.01			
Backwater Area (m^2)	R4 = 11,488-0.58 * Days	0.07	0.25			
Backwater Area (m^2)	R5 = 18,600 - 1.71 * Days	0.36	0.003			
Backwater Area (m^2)	R6 = 20.1 + 0.0000 * Days	0.00	0.98			
Backwater Area (m^2)	Total = 67,886 - 6.33 * Days	0.37	0.002	Total = 63,425 - 6.35 * Days + 4.97 * Flow	0.39	0.002
Backwater Count (#)	R3 = 43.6 + .0028 * Days	0.06	0.27			
Backwater Count (#)	R4 = 21.9 + 0.0025 * Days	0.19	0.04			
Backwater Count (#)	R5 = 39.1 -0.001 * Days	0.02	0.54			
Backwater Count (#)	R6 = 24.4 - 0.0006 * Days	0.50	<0.001			
Backwater Count (#)	Total = 124.7 + 0.0043 * Days	0.03	0.41	Total =102.9 +0.004 * Days + 0.02 * Flow	0.04	0.66
Island Count (#)	R3 = 79.6 - 0.0027 * Days	0.12	0.11			
Island Count (#)	R4 = 75.0 - 0.0052 * Days	0.57	<0.001			
Island Count (#)	R5 = 97.1 - 0.003 * Days	0.07	0.22			
Island Count (#)	R6 = 68.7 - 0.002 * Days	0.10	0.14			
Island Count (#)	Total = 321 - 0.126 * Days	0.21	0.03	Total = 197 - 0.02 * Days + 0.15 * Flow	0.58	<0.001
Island Area (m^2)	R3 = 1,536,512 - 16.8 * Days	0.02	0.49			
Island Area (m^2)	R4 = 1,728,839 + 24.4 * Days	0.02	0.53			
Island Area (m^2)	R5 = 4,277,658 - 11.35 * Days	0	0.9			
Island Area (m^2)	R6 = 1,147,188 - 41.2 * Days	0.21	0.03			
Island Area (m^2)	Total = 8,398,978 - 27.5 * Days	0	0.86	Total = 3,304,086 - 0.08 * Days + 0.74 * Flow	0.55	<0.001
Island Perimeter (m)	R3 = 46,203 - 1.25 * Days	0.23	0.03			
Island Perimeter (m)	R4 = 45,674 - 1.22 * Days	0.23	0.03			
Island Perimeter (m)	R5 = 70,695 - 2.47 * Days	0.36	0.003			
Island Perimeter (m)	R6 = 28,210 - 0.73 * Days	0.15	0.08			
Island Perimeter (m)	Total = 190,785 - 5.66 * Days	0.32	0.01	Total = 127,436 - 0.48 * Days + 0.52 * Flow	0.58	<0.001
Total Wetted Area (m^2)	R3 = 4,215,004 - 66.5 * Days	0.33	0.01			
Total Wetted Area (m^2)	R4 = 2,787,084 - 47.74 * Days	0.46	<0.001			
Total Wetted Area (m^2)	R5 = 2,634,400 - 51.9 * Days	0.47	<0.001			
Total Wetted Area (m^2)	R6 = 2,403,552 * Days	0.37	0.002			
Total Wetted Area (m^2)	Total = 12,040,041 - 209.3 * Days	0.44	<0.001	Total = 10,138,753 - 0.69 * Flow + 0.60 * Days	0.80	<0.001
n=22				n=22		

Table 18: The results of the simple linear regression model where x was time (expressed as days from December 1, 1992) and y was channel type. Regressions were done for each reach as well as the entire non-canyon section (Reach 3-6). In addition, a multiple linear regression was performed with both time and flow independent variables.

San Juan River Non-Normalized Channel Type Data

Channel Type	Equation : Y = a + b(Days)	r^2	p	Equation : Y = a + b(Days)+c(Flow)	r^2	p
Secondary Channel Split	R3 = 32.4 - 0.0015 * Days	0.67	<0.001			
Secondary Channel Split	R4 = 24.3 - 0.0010 * Days	0.52	<0.001			
Secondary Channel Split	R5 = 26.8 - 0.0016 * Days	0.69	<0.001			
Secondary Channel Split	R6 = 6.7 + 0.0002 * Days	0.10	0.14			
Secondary Channel Split	Total = 90.2 - 0.0039 * Days	0.71	<0.001	Total = 86.8 - 0.0039 * Days + 0.024 * Flow	0.71	<0.001
Main Channel Split	R3 = 9.5 - 0.0002 * Days	0.32	0.01			
Main Channel Split	R4 = 10.0 - 0.0003 * Days	0.56	<0.001			
Main Channel Split	R5 = 12.0 - 0.0004 * Days	0.69	<0.001			
Main Channel Split	R6 = 24.4 - 0.0006 * Days	0.50	<0.001			
Main Channel Split	Total = 55.9 - 0.0016 * Days	0.68	<0.001	Total = 54.52 - 0.0016 * Days + 0.00096 * Flow	0.69	<0.001
Island Split	R3 = 15.3 - 0.0004 * Days	0.26	0.02			
Island Split	R4 = 18.3 - 0.0014 * Days	0.72	<0.001			
Island Split	R5 = 28.9 - 0.0017 * Days	0.70	<0.001			
Island Split	R6 = 14.3 - 0.0011 * Days	0.60	<0.001			
Island Split	Total = 76.9 - 0.0046 * Days	0.87	<0.001	Total = 72.7 - 0.0046 * Days + 0.0029 * Flow	0.87	<0.001
Cobble/Sand Bar Channel Split	R3 = 33.8 + 0.0004 * Days	0.08	0.2			
Cobble/Sand Bar Channel Split	R4 = 27.1 + 0.0003 * Days	0.04	0.36			
Cobble/Sand Bar Channel Split	R5 = 18.2 + 0.0009 * Days	0.54	<0.001			
Cobble/Sand Bar Channel Split	R6 = 22.5 + 0.0003 * Days	0.09	0.18			
Cobble/Sand Bar Channel Split	Total = 101.5 + 0.0018 * Days	0.39	0.002	Total = 103.1 + 0.0018 * Days - 0.0011 * Flow	0.34	0.02
n=22				n=22		

Table 19: The results of the simple linear regression model where x was time (expressed as days from December 1, 1992) and y was habitat features. Regressions were done for each reach as well as the entire non-canyon section (Reach 3-6). Habitat data has been adjusted using the residuals from the flow covariate.

San Juan River Habitat Data Normalized to 915 cfs

Habitat Type	Equation : Y = a + b(Days)	r^2	p
Backwater Area (m^2)	R3 = 28,192 - 3.0639 * Days	0.33	0.01
Backwater Area (m^2)	R4 = 11,450 - 0.57 * Days	0.06	0.25
Backwater Area (m^2)	R5 = 18,486 - 1.67 * Days	0.37	0.002
Backwater Area (m^2)	R6 = 9,847 - 1.03 * Days	0.19	0.04
Backwater Area (m^2)	Total = 67,904 - 6.34 * Days	0.37	0.002
Backwater Count (#)	R3 = 44.2 + 0.0026 * Days	0.06	0.28
Backwater Count (#)	R4 = 22.02 + 0.0024 * Days	0.19	0.04
Backwater Count (#)	R5 = 39.1 - 0.0010 * Days	0.02	0.54
Backwater Count (#)	R6 = 19.9 + 0.0001 * Days	0.00	0.96
Backwater Count (#)	Total = 125.2 + 0.0041 * Days	0.03	0.43
Island Count (#)	R3 = 80.3 - 0.0029 * Days	0.18	0.05
Island Count (#)	R4 = 75.6 - 0.0053 * Days	0.78	<0.001
Island Count (#)	R5 = 98.4 - 0.0030 * Days	0.21	0.03
Island Count (#)	R6 = 69.5 - 0.0023 * Days	0.25	0.02
Island Count (#)	Total = 323 - 0.014 * Days	0.44	<0.001
Island Area (m^2)	R3 = 1,549,903 - 20.7 * Days	0.06	0.28
Island Area (m^2)	R4 = 1,753,484 + 17.3 * Days	0.02	0.52
Island Area (m^2)	R5 = 4,337,339 - 28.6 * Days	0.01	0.68
Island Area (m^2)	R6 = 1,155,907 - 43.7 * Days	0.3	0.01
Island Area (m^2)	Total = 8,504,565 - 58.0* Days	0.02	0.58
Island Perimeter (m)	R3 = 45,411 - 1.04 * Days	0.21	0.03
Island Perimeter (m)	R4 = 44,658 - 0.96 * Days	0.24	0.02
Island Perimeter (m)	R5 = 69,408 - 2.2 * Days	0.36	0.002
Island Perimeter (m)	R6 = 27,677 - 0.59 * Days	0.12	0.11
Island Perimeter (m)	Total = 187,155 - 4.7 * Days	0.34	0.004
Total Wetted Area (m^2)	R3 = 4,228,837 - 70.5 * Days	0.61	<0.001
Total Wetted Area (m^2)	R4 = 2,794,230 - 49.8 * Days	0.7	<0.001
Total Wetted Area (m^2)	R5 = 2,641,623 - 53.9 * Days	0.68	<0.001
Total Wetted Area (m^2)	R6 = 2,409,300 - 44.8 * Days	0.49	<0.001
Total Wetted Area (m^2)	Total = 12,073,991 - 219.12 * Days	0.7	<0.001

n=22

Table 20: The results of the simple linear regression model where x was time (expressed as days from December 1, 1992) and y was habitat features. Regressions were done for each reach as well as the entire non-canyon section (Reach 3-6). Habitat data has been adjusted using the residuals from the flow covariate.

San Juan River Channel Type Data Normalized to 915 cfs

Channel Type	Equation : Y = a + b(Days)	r^2	p
Secondary Channel Split	R3 = 31.9 - 0.0015 * Days	0.68	<0.001
Secondary Channel Split	R4 = 23.96- 0.0010 * Days	0.52	<0.001
Secondary Channel Split	R5 = 26.30 - 0.0016 * Days	0.7	<0.001
Secondary Channel Split	R6 = 6.72 + 0.0002 * Days	0.10	0.14
Secondary Channel Split	Total = 88.9 - 0.0038 * Days	0.71	<0.001
Main Channel Split	R3 = 9.5 - 0.0002 * Days	0.33	0.01
Main Channel Split	R4 = 9.9- 0.0003 * Days	0.56	<0.001
Main Channel Split	R5 = 11.9 - 0.0004 * Days	0.69	<0.001
Main Channel Split	R6 = 24.2 - 0.0006 * Days	0.50	<0.001
Main Channel Split	Total = 55.4 - 0.0015 * Days	0.69	<0.001
Island Split	R3 = 15.2 - 0.0004 * Days	0.26	0.02
Island Split	R4 = 17.8 - 0.0014 * Days	0.72	<0.001
Island Split	R5 = 28.3 - 0.0017 * Days	0.70	<0.001
Island Split	R6 = 13.95 - 0.0011 * Days	0.61	<0.001
Island Split	Total = 75.3 - 0.0046 * Days	0.87	<0.001
Cobble/Sand Bar Channel Split	R3 = 33.9 + 0.0004 * Days	0.08	0.2
Cobble/Sand Bar Channel Split	R4 = 27.2 + 0.0003 * Days	0.04	0.37
Cobble/Sand Bar Channel Split	R5 = 18.4 + 0.0009 * Days	0.55	<0.001
Cobble/Sand Bar Channel Split	R6 = 22.6 + 0.0003 * Days	0.09	0.17
Cobble/Sand Bar Channel Split	Total = 102.12 + 0.0018 * Days	0.40	0.001

n=22

Table 21: The results of the multiple linear regressions using habitat as the dependent variable and three subsets of independent variables. All habitat data are from baseflows <1,500

ALL POTENTIAL INDEPENDENT VARIABLES
BASEFLOW (<1,500 cfs)

		*Equation: y = A + B * (x) + C * (y) + D * (z)*	r^2	p
Secondary Channel Splits (#)	=	73.94 - 0.004 * (Days) + 0.035 * (Flow) -0.188 * (Days<500) - 0.0014 *(Max Flow)	0.86	<0.001
Main Channel Splits (#)	=	56.17 - 0.004 * (Days) -0.023 * (Days <750)	0.76	<0.001
Island Splits (#)	=	46.73 -0.004 * (Days) + 0.025 * (Flow) + 0.401 * (Days BT 2,000-2,500)	0.93	<0.001
Cobble/Sand Bar Splits (#)	=	76.65 +0.002 * (Days) + 0.42 * (Days BT 1,500-2,000) + 0.076 * (Days BT 750-1,000) + 0.01 * (Flow)	0.82	<0.001
Backwater Area (m2)	=	20,478 + 0.059 * (Decending RO)	0.58	<0.001
Backwater Counts (#)	=	160 - 0.919 * (Days < 500)	0.15	0.08
Island Count (#)	=	138 + 0.202 * (Flow) - 0.014 * (Days)	0.70	<0.001
Island Area (m2)	=	5,398,676 + 3,970 * (Flow) - 5,668 * (Days < 750)	0.77	<0.001
Island Perimeter (m)	=	116,511 + 84.3 * (Flow) - 6.22 * (Days)	0.80	<0.001
Total Wetted Area (m2)	=	10,569,824 - 2,353 * (Days BT 500-1,000) + 1,949 * (Flow) - 176 * (Days)	0.82	<0.001

n=22

ONLY ANTECEDENT CONDITION INDEPENDENT VARIABLES
BASEFLOW (<1,500 cfs)

			r^2	p
Secondary Channel Splits (#)	=	86.9 - 0.11 * (Days < 750)	0.41	0.001
Main Channel Splits (#)	=	59.3 - 0.053 * (Days BT 500-1,000)	0.59	<0.001
Island Splits (#)	=	85.5 -0.149 * (Days BT 500-1,000)	0.59	<0.001
Cobble/Sand Bar Splits (#)	=	80.5 + 0.703 * (Days BT 1,500-2,000) + 0.078 * (Days BT 500-1,000)	0.55	<0.001
Backwater Area (m2)	=	20,478 + 0.059 * (Decending RO)	0.58	<0.001
Backwater Counts (#)	=	160 - 0.919 * (Days < 500)	0.15	0.08
Island Count (#)	=	343 - 0.39 * (Days BT 500-1,000)	0.16	0.06
Island Area (m2)	=	9,968 - 7,943 * (Days <1,000)	0.29	0.01
Island Perimeter (m)	=	209,678 - 216 * (Days BT 500-1,000)	0.31	0.01
Total Wetted Area (m2)	=	12,695,250 - 7,822 * (Days BT 500-1,000)	0.46	<0.001

n=22

All VARIABLES INCLUDING GEOMORPHIC FEATURES
BASEFLOW (<1,500 cfs)

			r^2	p
Backwater Area (m2)	=	8,426 +0.07 * (Decending RO) + 186 * (Island Count) - 730 * (Island Splits)	0.76	<0.001
Backwater Counts (#)	=	160 - 0.919 * (Days < 500)	0.15	0.08
Total Wetted Area (m2)	=	10,085,022 + 0.78 * (SC) - 0.14 * (CB/SB) - 0.21 * (Days BT 500-1,000)	0.90	<0.001

n=22

Table 22: Mean daily peak flow having a recurrence interval of 1.5 years ($Q_{1.5}$) for Archuleta (USGS Station 09355500) and Farmington (USGS Station 09365000) for the period of record for the pre Navajo Dam interval, post Navajo Dam (pre SJRIP) interval and the Post Dam SJRIP interval

Location	Recurrance Interval $Q_{1.5}$	Pre-Dam	Post Dam Pre-SJRIP		Post Dam SJRIP	
		(1955-1962)	(1963-1991)		(1992-2015)	
		cfs	cfs	Pre to Post Dam % Reduction	cfs	Pre to Post Dam % Reduction
Archuleta	1.5	4,816	1,889	-61%	2,927	-39%
Farmington	1.5	9,111	6,038	-34%	6,886	-24%

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